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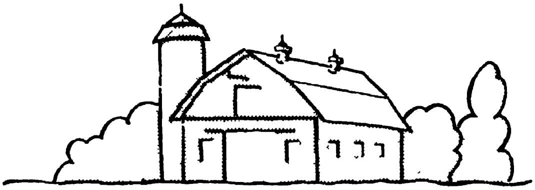
United States Department of
Agriculture . . . . .

YEARBOOK OF AGRICULTURE
1939

FOOD and LIFE



Yearbook of Agriculture

1939

UNITED STATES DEPARTMENT OF AGRICULTURE

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FOREWORD

OF ALL the sciences and arts one of the greatest is the feeding of animals and human beings. Forty years ago the scientists thought the problem was simple— discover the needs for protein, fats, carbohydrates, and a few minerals, analyze the foods for these substances, and then so blend the foods as to furnish an adequate supply of each. Today we know that there is much more to it than this. The old science is still fundamental, but the new science is continually adding to it knowledge of a whole array of substances- minerals, vitamins, amino acids —needed by the body.

In ordinary diets, both animal and human, that contain a wide variety of natural foods, most of the essential substances are present in adequate quantities. But under certain conditions, when the choice of foods is limited, the diets customarily followed cause inefficiency, sickness, or even premature death. The lack of common-sense knowledge of nutrition even among many well-to-do people in the United States is appalling. There are many kinds of "hidden hungers" which the experienced person can read in the faces and attitudes of the undernourished. Peaked faces, bowlegs, and shaky nervous systems are only a few of the manifestations.

Two-thirds of this book deals with the nutrition of animals and only one-third with that of human beings; nevertheless, even the animal section contains much information of fundamental value with regard to human nutrition. The reverse is true too. The animal body and the human body are astonishingly alike in their reactions to the necessary substances in foods. The modern knowledge of human nutrition is based to a large extent on animal experimentation.

Probably 99 percent of the children of the United States have a heredity good enough to enable them to become productive workers and excellent citizens provided they are given the right kind of food, proper training, and ordinary opportunities. Fundamental to adequate training and decent opportunity is food. Fifty percent of the people of the United States do not get enough in the way of dairy products, fruits, and vegetables to enable them to enjoy full vigor and health, and a large number of them do not get enough because they cannot afford it. It is the duty of the farmers, the Government, the businessmen, and organized labor to cooperate to see that the children of these people are better fed than their parents were.

That part of the book which deals with human nutrition is an effort to discover a scientific basis for coordinated action along this line. The Department of Agriculture publishes the book realizing that the science of nutrition is still very incomplete and that much new, vital information is being discovered every year. But a comprehensive knowledge of nutrition is far from widespread. We feel that it is wise to publish this book, in spite of its shortcomings, because it is comprehensive. It shows that the human being and the animal have fundamentally the same needs. People as well as animals must be well fed if they are to do their best and give their best.

HENRY A. WALLACE,
Secretary of Agriculture.

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Soils and Men

CONTENTS

Page

Foreword v
Henry A. Wallace

Yearbook Committee on Nutrition vii

Food and Life—A Summary 3
Gove Hambidge

Part 1 • HUMAN NUTRITION

From Tradition to Science 97
Louise Stanley

Food Functions and the Relation of Food to Health. . 100
Lela E. Booher, Callie Mae Coons

Food Habits, Old and New. 124
Hazel K. Stiebeling

Can Food Habits be Changed? 131
Paul E. Howe

Food Fads, Facts, and Fancies 139
Helen S. Mitchell

The White Rat as a Contributor to Science. . . . 145
M. H. Friedman

Human Food Requirements—Carbohydrates, Fats, Energy 152
Helen S. Mitchell, Jane G. Lease, Nancy B. Morey

Protein Requirements of Man 173
D. Breese Jones

Mineral Needs of Man 187
Henry C. Sherman, Mabel A. Dickson, Margaret·Cammack Smith, Esther Peterson Daniel

Vitamin Needs of Man 221
Lela E. Booher, Elizabeth C. Callison, O. L. Kline, Sybil L. Smith, Frederick W. Irish, E. M. Nelson

Food Composition 272
Charlotte Chatfield, Georgian Adams

Vitamin Content of Foods 286
Esther Peterson Daniel

Present-Day Diets in the United States 296
Hazel K. Stiebeling, Callie Mae Coons

Planning for Good Nutrition 321
Hazel K. Stiebeling, Faith Clark

Micro-organisms in Foods and Food Preservation. . 341
Harry E. Goresline

Enzymes in Foods and Food Preservation. . . . 350
A. K. Balls

United States Meat Inspection. 355
E. C. Joss

Supervision and Inspection of Milk. 360
Ernest Kelly

Food Grades and the Consumer. 364
Marius Farioletti

What the Modern Homemaker Needs to Know. . . 372
Miriam Birdseye

Better Nutrition as a National Goal. 380
Hazel K. Stiebeling, Marius Farioletti, F. V. Waugh, J. P. Cavin

Part 2 • ANIMAL NUTRITION

Sources and Cycles of the Nutritive Elements . . . 405
E. J. Kraus

The Digestive Processes in Domestic Animals . . 418
H. W. Schoening

Factors Affecting Maintenance Nutrition, Feed Utilization, and Health of Farm Animals 431
Louis L. Madsen

Growth, Fattening, and Meat Production . . . 450
O. G. Hankins, Harry W. Titus

Some Effects of Nutritional Levels 469
Paul E. Howe

The Relation of Diet to Reproduction 476
Ralph W. Phillips, M. H. Friedman, W. A. Turner

Relation of Nutrition to the Production of Hides and Wool 492
John I. Hardy, Imogene P. Earle

The Nutrition of Very Young Animals 501
Imogene P. Earle

Nutritional Requirements of Beef and Dual-Purpose Cattle 519
W. H. Black, Bradford Knapp, Jr., J. R. Douglas

Practices in the Feeding of Beef and Dual-Purpose Cattle 544
W. H. Black

The Feeding of Dairy Cows for Intensive Milk Production in Practice 566
Edward B. Meigs

Figuring the Rations of Dairy Cows 592
T. E. Woodward

Practical Feeding and Nutritional Requirements of Young Dairy Stock 597
Joseph B. Shepherd, H. T. Converse

Variations in the Composition of Milk 639
P. A. Wright, E. F. Deysher, C. A. Cary

Utilization of Feed Energy and Feed Protein in Milk Secretion 649
C. A. Cary

The Vitamins in Milk and in Milk Production . . . 668
C. A. Cary

Glands, Hormones, and Blood Constituents—Their Relation to Milk Secretion 685
M. H. Friedman, C. A. Cary

Milk in Nutritional Research—A Sketch of Progress . 699
C. A. Cary

Nutritive Requirements of Swine 706
N. R. Ellis, J. H. Zeller

Practices in Swine Feeding 723
J. H. Zeller, N. R. Ellis

Feeding Problems with Sheep 746
Damon A. Spencer

Feeding Problems with Goats 758
Damon A. Spencer

Nutrition of Horses and Mules 763
Earl B. Krantz, S. R. Speelman

Practical Nutritive Requirements of Poultry . . . 787
Harry W. Titus

Practical Feeding of Poultry 819
Harry W. Titus

Nutritional Requirements of Dogs 844
Imogene P. Earle

Feeding Dogs 856
S. R. Speelman

Nutrition of Fur Animals 871
Charles E. Kellogg

Feeding Requirements of Gallinaceous Upland Game Birds 893
Ralph B. Nestler

Pasture and Range in Livestock Feeding 925
P. V. Cardon, W. R. Chapline, T. E. Woodward, E. W. McComas, C. R. Enlow

The Nutritive Value of Harvested Forages . . . 956
T. E. Woodward, W. H. Hosterman, P. V. Cardon, E. W. McComas

Losses in Making Hay and Silage 992
J. A. LeClerc

Nutritive Value of Miscellaneous Feeds 1017
E. W. McComas, T. E. Woodward

Deficient and Excess Minerals in Forage in the United States 1027
A. M. Hartman

What Do We Need to Know in Livestock Nutrition? . 1045
O. E. Reed

Composition of the Principal Feedstuffs Used for Livestock 1065
N. R. Ellis, W. R. Kauffman, C. O. Miller

Literature Cited 1075

Index 1143

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TO THE MEMORY OF

Wilbur Olin Atwater

1844 · 1907

W. O. ATWATER, who organized the Office of Experiment Stations in the United States Department of Agriculture, was one of the pioneers in modern nutrition. He headed the nutrition investigations carried on by various State experiment stations in cooperation with the Department, and in his own laboratory he conducted a remarkable amount of fundamental investigation on the composition of food materials and their effects on the body. His bulletin, The Chemical Composition of American Food Materials, has been in demand all over the world since 1899. The method of measuring the energy content of foods and the energy needs of the body by means of calorimeters was largely the result of his work. He conducted far-sighted surveys of American dietaries and national food habits and wrote or supervised popular bulletins on foods and food values. His high scientific standards, breadth of vision, and enthusiasm influenced not only his own associates, but many others who are carrying on this work today.

A Summary

FOOD AND LIFE

IN THE PAST, science has conferred on those peoples who availed themselves of the newer knowledge of infectious diseases, better health and a greater average length of life. In the future, it promises to those races who will take advantage of the newer knowledge of nutrition, a larger stature, greater vigor, increased longevity, and a higher level of cultural attainment. To a measurable degree, man is now master of his own destiny where once he was subject only to the grim hand of Fate.

JAMES S. MCLESTER.
Nutrition and the Future of Man.

FOOD AND LIFE— A SUMMARY

by Gove Hambidge [1]

THE RETINA, or seeing part of the eye, contains two kinds of structures that are senstitive to light. One kind is in the form of tiny rods and the other kind in the form of tiny cones. We "see" because these rods and cones contain light-sensitive substances, just as a photographic film is coated with a substance sensitive to light. The rods are particularly important for vision in dim light and the cones in bright light.

When light strikes those rods or cones, substances are broken down chemically, and products are formed that stimulate the nerve endings of the eye. The stimulated nerves then carry a message to the brain, and this is what we call seeing. Meanwhile the products formed by the chemical break-down keep recombining to form the first substances over again so that the eyes will be continuously sensitive to light.

The substance in the rods, sensitive to dim light, is called visual purple. This purple substance contains vitamin A, which our bodies get from food. When dim light strikes the visual purple, it becomes bleached in the process of chemical change, and the vitamin A is released. If more visual purple is to be formed to keep the eyes sensitive to dim light, there must be a continuous supply of vitamin A. If the body has very little vitamin A, the visual purple will be slow in forming, and the eyes will not readily adapt themselves to dim light. If there is still less vitamin A, the rods may not be able to function at all and the eyes will be completely blind in dim light.

The body makes its supply of vitamin A from a yellow substance in plant foods, called carotene. It can also get vitamin A ready-made from certain oils or fats in animal foods—butterfat, for instance. During the World War, Denmark exported its butter because of the war demand and substituted other fats in the diet. Blindness, caused by lack of vitamin A, began to show up among Danish children. Their eyesight had been sold abroad with the butter.

Nothing illustrates better than this what minerals and vitamins and other substances in foods do for us, and how vital they are to our bodies in a thousand different ways. Automobile drivers whose eyes lack sufficient vitamin A may cause accidents at night; but this is only one of many effects of vitamin A deficiency, and others are perhaps even more serious. Moreover, it is possible to go down the whole list of necessary minerals and vitamins and find one thing after another just as important as this function of vitamin A.

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[1] Gove Hambidge is Principal Research Writer, Office of Information.

These things are recent discoveries, and not all of them are known as clearly as the relation of vitamin A to the visual purple in the rods of the eyes. But they show what the lusty young science of nutrition is doing in our time. Like vitamin A itself, this science is enabling us to see in a dim light.

This book, which is a product of the newer knowledge of nutrition, is the fourth in a series of Yearbooks of Agriculture dealing with major aspects of modern farming. Two Yearbooks on genetics and breeding, under the title of Better Plants and Animals, were published in 1936 and 1937. The 1938 Yearbook was devoted to the subject of its title, Soils and Men.

Like its predecessors, the 1939 Yearbook has many shortcomings. It is incomplete not only because knowledge is incomplete, but because agricultural scientists are busy folk whose experimental work cannot stop, so that they have to sandwich in their writing at nights and on week ends and holidays. It is a mixed collection of somewhat miscellaneous articles rather than a continuous book partly because so many people contribute to it and partly because it must be prepared in the short period of a year. For the same reasons, it is uneven in quality. Yet with all its imperfections, it seems worth doing.

The present book is unique in that it combines the nutrition of human beings and of farm livestock in a single volume. For farmers, that is a logical thing to do. City people have to think only of feeding themselves. The farmer has to think of the needs of his animals as well as of his own family. Human nutrition throws much light on the nutrition of animals, and animal nutrition throws much light on the nutrition of human beings. In this book, for example, the reader will have to refer to certain articles in the section on human nutrition for fundamental facts about the various life substances in foods. This merely reflects what has actually happened in research. Discoveries in each field are continually adding knowledge to the other.

The statement that the farmer has to think of the needs of his animals as well as of his own family might be put in reverse. He should think of the needs of himself and his family as well as those of his animals. Many a man will study nights to find out how his cows or hogs or chickens should be fed and go to infinite pains to give them balanced rations, yet fail to have a glimmering of a notion that the diets of human beings must be balanced in just the same way. This is especially true in modern commercial farming, where all the emphasis is placed on producing for the market.

Because of his acquaintance with livestock, the farmer should be the first to realize the importance of nutrition to human beings. Farmers unfortunately have the smallest share of the national wealth, but it is within their power to have the largest share of the national health. To a certain extent they do have this now, as this book shows; but they could do much more. Production for the market is subject to violent ups and downs. Sometimes it involves more loss than profit. Producing for home consumption gives steady returns in physical well-being year after year, no matter what happens to the market. Farmers can have far-and-away the best diets in the United States if they want to.

This is not said to minimize the importance of fair market returns to farmers. But a man should at least use the treasures in his own back yard while he is looking for treasures elsewhere. A healthful diet for his family is one treasure the farmer can find in his own back yard, in his garden, his orchard, his pasture, his hen house, his barn. City people cannot have these things. They have to depend entirely on what they can afford to buy at the store.

If the farmer should be the first to see the importance of nutrition to his own family, by the same token he should be the first to see its importance to the Nation as a whole. Any livestock man knows that it costs more to feed an animal well than to let it starve along. It requires more feed and a greater variety of feed. It also costs more to feed human beings well than to let them starve along. Now a great many people in the United States are starving along, more or less; half of them, according to recent surveys, do not have even fair diets, and only a small percentage have good diets. This is something that is up the farmer's alley. He is the one who produces the food for these people. If millions more of them could have good diets, he would be the gainer (provided, of course, that he could get fair prices). For purely selfish as well as humanitarian reasons, he above all people should be in favor of raising the standard of nutrition in every city and town and village. The immense surpluses of many farm products could be wiped out if enough people could be well nourished. In fact, farmers would have to produce larger quantities of some of the very products that are now surpluses.

So the science of nutrition has wide implications. Vitamins are not interesting curiosities of the laboratory. They are matters of life and death to the individual, and they are tied in with the well-being of agriculture and the vigor and strength of the Nation.

This book will have fulfilled its function if it helps farmers to understand these things, and if it throws a little light on the principles of good nutrition for both human beings and their livestock.

GENERAL LAY-OUT OF THE BOOK

As in the case of the previous Yearbooks in this series, the volume contains both technical and nontechnical material, so that it will be useful to different groups of readers.

Part 1 deals with human nutrition. First there is an introduction to this section; then an article giving the main facts about the functions of the nutrients in foods; then a group of general articles on human attitudes toward food. Next there are four articles on human requirements for carbohydrates, fats, energy, protein, minerals, and vitamins. These articles cover more than requirements, however; they tell a good deal about the nature and functions of the substances they deal with, and some of this information is basic in animal as well as human nutrition. Following them, two articles deal with the content of these nutrients in actual food materials. Then comes an article analyzing our present diets in the United States, and one showing how these diets could be improved by practical methods that almost anyone can follow. Next there is a group of articles on subjects relating to food preservation and consumer safeguards. The section ends with discussions of the broad economic aspects of nutrition in the United States.

Part 2 deals with animal nutrition. An introductory article gives some fundamentals that connect soil and plant management with animal and human nutrition; and this is followed by an article on the digestive processes of animals. Next, a series of articles gives the relation of diet to maintenance, health, growth, fattening, meat production, reproduction, and the production of wool and hides. The nutrition of young and orphan animals is then considered. Following this there are single articles and groups of articles dealing specifically with the nutrition and feeding of various classes of livestock—beef cattle, dairy cattle, swine, sheep, goats, horses, and poultry. Dogs, fur animals, and certain game birds are included because of the general interest in these animals. Next there is a group of articles on the principal livestock feeds available to farmers. A research survey follows, showing what is actually being done in the way of experimental work in the various State experiment stations, and also what research workers stress as the needs of the future. A set of tables at the end of the book gives up-to-date figures on the composition of the principal feedstuffs.

All of the articles are summarized editorially in the following pages of this introduction except the research survey, the study of soil deficiencies, and the tables of composition of feedstuffs.

PART 1. HUMAN NUTRITION

FROM TRADITION TO SCIENCE

Man inherits certain possibilities. How they develop depends on his environment; and the most fundamental influence in the environment is food. It builds and shapes his body, and through the glands, hormones, and nervous system it modifies his mental and emotional make-up. All food comes directly or indirectly from the soil. Soils differ in different areas, and some soils furnish an abundance of certain elements that other soils lack. Since primitive man had to get his food supply entirely from local sources, these differences in the make-up of soils must, through long ages, have influenced the physical and perhaps even the mental and emotional characteristics of different tribes and races. They must have been a powerful influence in the evolution of man.

Food habits and traditions were built up through the selection of those foods in each area that proved to have value for keeping people alive and well. Even today, among primitive people and peasants living on the land, certain traditional combinations of foods are found, on examination, to be based on good scientific principles. Long before vitamins or minerals were discovered, various foods were known to cure or prevent certain diseases. In the thirteenth century, for example, the ash of burned sponges was used to treat goiter. Five or six hundred years later a chemist found that there was iodine in this ash.

Such food habits were developed by trial and error, over long periods, with much suffering by the way. But men had one thing in their favor. The foods used were natural, whole foods, furnishing the essentials for human nutrition. Today the situation in a modern industrial country is entirely different. Comparatively few people produce their own food. Production and distribution are commercialized. There is a greater variety of foods, transported over greater distances; but many of them are processed and refined so that they have lost the elements they contained in their natural state. Moreover, when people buy their food instead of producing it, the economic factor has a more powerful influence on the kind of diet they get. In this situation, tradition and habit are no longer safe guides to the selection of foods. They can lead to dangerous mistakes.

But paralleling modern developments in the food industries there have been developments in knowledge of nutrition. This knowledge, rightly understood and used, furnishes a safe guide in the complex food situation of today. It shows what man needs to get from food and how to get it by proper selection and preparation of foodstuffs. This science of nutrition does not wipe out habits and traditions. It supplements them, corrects them, and shows how to use them intelligently. It offers a sound foundation for the food production and distribution of the future.

FOOD FUNCTIONS AND THE RELATION OF FOOD TO HEALTH

Considered as a machine using the energy from fuel, the human body is about as efficient as an automobile engine and 16 to 25 percent more efficient than a steam locomotive. The fuel the body uses comes from the starches and sugars (carbohydrates), the fats, and the proteins in food. Carbohydrates and proteins are about equal in fuel value; fats furnish more than twice as much energy as either. Before the stored energy in foods becomes available, they must first be broken down into simple substances in the digestive system, then carried to various parts of the body in the blood stream, and finally burned—that is, combined with oxygen, which is brought from the lungs to all parts of the body by the hemoglobin or red coloring matter in the blood. The whole complex process by which foods are broken down and utilized in the body is called metabolism.

A moderately active person uses about half the energy he gets from food just for staying alive—keeping the body at normal heat and the internal organs going. This minimum use of energy by the body for maintenance is called the basal metabolism. Any physical movement whatever, even lifting the little finger, demands an additional use of energy over that involved in basal metabolism. Food energy taken in above that required for basal metabolism and activity is stored as fat. Taking 10 percent more calories a day than are needed—say as an extra helping of dessert—may add 20 pounds of fat a year to the body. Except in conditions caused by glandular disturbances or illness, maintaining the right weight is a matter of adjusting food to exercise, or vice versa. Growing children should be a little over the average weight for their age and size. Adults past 30 should perhaps be a little under the average.

In addition to supplying energy, foods furnish the materials for building and repairing the body and regulating its many internal activities. A varied and well-balanced diet is necessary to furnish everything required for these innumerable and very complex functions. Most authorities agree that, for an adult, about 60 percent of the food calories should be in the form of starches and sugars, about 25 to 30 percent in the form of fat, and about 10 to 12 percent in the form of protein. In addition, a wide range of minerals and vitamins must be supplied. All this can be done by a well-balanced diet that includes fresh fruits and vegetables, whole cereals, milk, meat, and eggs. Failure to provide enough of any essential food element brings such results as impaired efficiency, poor growth, susceptibility to disease, and, in severe cases, death. Moreover, it is possible to suffer from malnutrition without showing clear-cut signs of any of the well-known dietary deficiency diseases. There are many border-line cases in which extreme symptoms do not appear.

Whether water is considered as a food depends on the point of view. It is necessary for the body, at any rate. Many foods are more than half water, and the body gets some water also from the burning of sugars, fats, and protein. A normal man of average size loses about 1½ pints of water a day as "insensible perspiration"—vapor from the skin and lungs. Ten pints may be lost in an hour as sweat during hard exercise. Two to five pints a day are excreted by the kidneys and bowels. Suppose the average total loss under certain normal conditions is 6 pints every 24 hours. About 4 pints will be taken in with a normal mixed diet. This leaves about 2 pints or 4 glasses to be drunk as water. No general recommendations for drinking any specific amount of water every day can be made, however. Perhaps thirst is the best guide in most cases.

Excessive sweating removes salt from the body rapidly, and this may be a contributing cause of heat prostration. Taking extra salt to make up for this loss is now commonly advised for those undergoing hard exercise in great heat.

Next to water, protein makes up the largest part of living tissues. Digestion breaks protein down into simpler substances called amino acids, and these are carried by the blood to the places where they are needed for building and repairing the body. Here they are built into new proteins. Any amino acids not used in this way are broken down still further and partly burned as fuel. Animal proteins furnish certain necessary amino acids not found in sufficient quantity in most vegetable proteins, and animal products should therefore be included in the diet. A serious and prolonged deficiency of protein produces an edema or dropsy that was fairly common in Europe during the World War and has been known to occur among poor people in this country. It is especially important for growing children and pregnant and lactating women to have a liberal amount of protein.

Fats stored in the body are a reserve source of heat and energy and a protection against cold and injury around certain organs. In addition to the function of fats as fuel, certain kinds are believed, from experiments with animals, to be necessary in other ways for normal nutrition. The function of sugars and starches as fuel has already been mentioned. The blood normally contains about 0.1 percent of sugar as a steady supply for the body. In addition, carbohydrates are stored in the liver and muscles as glycogen, or "animal starch," which may be used to form sugar in the blood. This function is disturbed in some diseases, notably diabetes mellitus.

The minerals and inorganic materials that must be supplied by the diet include sodium, potassium, calcium, magnesium, iron, copper, manganese, sulfur, phosphorus, chlorine, iodine, and probably many others in small amounts. Of these, only four—calcium, phosphorus, iron, and iodine—are likely to be deficient in ordinary diets.

Calcium forms a large part of the bones and teeth, and it is necessary for normal blood clotting, the steady working of the heart, and normal muscular activity. Phosphorus is also liberally used in the bones and teeth, and it plays a vital part in some of the delicate chemical activities of the body, notably those that release energy from foods. Beginning at birth, children need a generous supply of these two minerals to meet the needs of growth. Evidence indicates, however, that many people of all ages do not get enough calcium. In children, a severe calcium deficiency stunts growth; among older people it sometimes causes "late rickets" (hunger osteomalacia). Among women, a contracted pelvis, which interferes with normal childbirth, may be caused by calcium deficiency. This condition was found in 12 percent of a group of women studied in congested districts of Glasgow. It occurred even among women who were well to do. Pregnant and lactating women, of course, need more calcium than average adults.

Iron is necessary for the formation of hemoglobin in the blood. Nutritional anemia is the penalty for an insufficient supply of iron. The disease is fairly common among infants, and it is an ever-present danger through adolescence, especially with girls. Copper in minute amounts must accompany iron for hemoglobin formation; perhaps also traces of cobalt and manganese.

Iodine is essential in the making of a secretion of the thyroid gland, thyroxin, which helps to regulate the heat production of the body. Simple goiter, which is most prevalent among women, especially during adolescence, pregnancy, and lactation, is the result of a lack of iodine. In regions where there is no iodine in the soil or water supply, it can be taken in salt or otherwise, but an overdose is easy to get, and harmful.

Many of the vitamins so far discovered are known to be vital to the health, even the life of human beings. Without sufficient vitamin A, the thin layer of epithelium, including the mucous membranes, that protects the organs of the body suffers disastrous changes, the teeth are affected, the eyes become less sensitive to dim light, growth is not normal. Without sufficient vitamin B_1, or thiamin, sugar is probably not properly oxidized in the body; there is a loss of appetite, a series of nervous disorders, and a disturbance of the heart—symptoms collectively known as beriberi, or polyneuritis. With insufficient vitamin C, or ascorbic acid, the material between the cells of the body no longer functions as it should, the teeth and bones suffer, minute blood vessels become fragile, and other symptoms of scurvy develop. Lack of vitamin D spells rickets in children; this vitamin is necessary for the proper functioning of calcium and phosphorus in building bones and teeth. Lack of vitamin G, or riboflavin, in experimental animals results in cessation of growth, loss of hair, nutritional cataract of the eyes, skin disorders. Lack of nicotinic acid (one of the B vitamins) is apparently the determining cause of pellagra—a disease of the shockingly ill-fed, usually the poor but sometimes the well to do. The newly discovered vitamin K is apparently necessary, with bile or bile salts, for normal blood clotting.

Does a good diet prevent infectious diseases as well as these nutritional diseases? No vitamin or other nutritive element, according to to the present view, gives any actual immunity to infection; but there is no doubt about the value of diet in promoting the resistance of the body against certain infectious diseases at least. Does a good diet increase length of life? Long-time experiments conducted by Sherman at Columbia University with rats indicate that it does; and, similarly, rat experiments conducted by McCollum at Johns Hopkins indicate that it increases vigor and well-being at all ages and postpones the usual signs of senility.

FOOD HABITS, OLD AND NEW

Among the great variety of food habits and traditions developed by people in different areas, some are good, some are bad. In a notable report by McCarrison, dealing with the foods of natives in India, people in the north, living on a diet of whole wheat, milk, legumes, vegetables, and some meat were described as "stalwart resolute races"; those in the south, living on a diet containing a large proportion of polished rice, some legumes, vegetables, and fruits, but little or no milk and meat, were described as "boneless, supine, and poorly developed." The British Medical Research Council reported on the physique and health of the Masai and the Akikuyu, two tribes in Kenya, Africa. The Masai ate mostly milk, meat, and raw blood, the Akikuyu mostly cereals, roots, and fruits. The average Masai male was 5 inches taller and 23 pounds heavier than the average Akikuyu and had 50 percent greater strength. Bony deformities, decayed teeth, anemia, lung diseases, and tropical ulcer were more prevalent among the Akikuyu. On the other hand, the Masai had more constipation and arthritis. Both tribes needed more vegetables; the Akikuyu needed more milk.

Compared with those in other countries, diets in the United States are generous. The second generation of Japanese in California and of Europeans in the larger American cities are larger and better built than their parents. American women entering colleges are an inch taller than those who entered college 30 years ago; in one men's college, the average height has increased about 2 inches in 60 years. Perhaps these are evidences of nutritional progress.

Certainly diets have changed in this country in two generations. Analysis shows that the proportion of calories derived from milk, cheese, fruits, and succulent vegetables has actually doubled in 50 years. There has also been a slightly greater emphasis on sugars and fats. Forty to fifty years ago, more than 80 percent of the food calories in American diets were derived from grains, meats, fats other than butter, sugars, potatoes, and mature legumes (the traditional white bread, meat, sugar, and potato diet).

In spite of changes, the proportion derived from these sources is still over 70 percent. Sherman says that 50 percent of the food calories should be derived from milk and milk products, fruits, vegetables, and eggs (as compared with less than a third in present American diets) and that at least half the grain products consumed should be in the form of whole grain (as compared with less than a fifth at present). Perhaps this is more or less an ideal, but it shows the trend of thinking of modern nutritionists, backed by a half-century of research which has seen the development of most of the knowledge of nutrition we now have. These nutritionists believe that if better diets became sufficiently widespread, most people could achieve the physical well-being that only the most fortunate now enjoy.

CAN FOOD HABITS BE CHANGED?

If some superdietitian could hand everyone a simple, perfectly balanced menu and get them to use it, much as a farmer feeds his cows, it would be a comparatively simple matter to have everyone well nourished. But it would be an unfortunate state of affairs, because we would then be cows or robots instead of human beings. As human beings, we expect to get emotional satisfactions from food as well as to meet our physical needs. These emotional satisfactions are often tied up with our habits, and we resist changes that we think might interfere with them. This is one reason why the problem of nutrition is complicated, as every mother knows if she has tried to teach a child to eat properly.

One of the great helps is to think of foods in terms of groups, each group being an especially good source of some one or more nutrients. Then it is not necessary to overemphasize some particular food in order to get something that may be lacking in the diet; any one of a number of foods in the same group can be used as well. This gives flexibility to menus and enables a skillful housewife to avoid what is especially disliked, as well as to maintain interest in the meals from day to day.

Hunger, which is due to actual contractions of the stomach, and appetite, which is stimulated by pleasant food odors and flavors, may be used to get new foods accepted. Outdoor exercise, physical work, and insufficient food create hunger, which helps to make new foods acceptable. Excitement, pain, or anger inhibit hunger and may therefore create resistance to new foods. Associating a certain food with an especially pleasant experience may "condition" us to accept it.

In the long run, the problem of building up good dietary habits is a problem of continuous education. It should begin in early childhood, with the mother who teaches the child to enjoy a simple, adequate diet, and to accept new foods. The schools too can carry on this work. Books, pamphlets, newspaper articles, and radio broadcasts designed for adults as well as children are all useful, provided they are accurate and unbiased. Recipes are especially worth while if they are accompanied by information about the place of the foods in the dietary. More attention should be paid to recipes for attractive, enjoyable dishes that encourage use of the cheaper forms of protective foods.

FOOD FADS, FACTS, AND FANCIES

Science always has its camp followers who clean up the scraps. The camp followers of nutrition are the quacks, the faddists, and the advertisers of fake nostrums. They use technical language so fluently that sometimes they almost fool themselves. Here are some common types of quackery to beware of:

"Health foods" advertised as panaceas for various ills, real or imaginary: There is no such thing as a "health food," and no one food is essential to health or has unique health-giving properties—especially the weird concoctions often sold under this name. The term "scientifically balanced food" is in the same class. No one food is "balanced" in the dietary sense. "Energy" foods, as the term is often used, also are fakes. Almost all foods furnish energy.

Products to control weight: These are of three types: (1) Those that speed up body processes so that food is burned faster, such as thyroid extract or dinitrophenol, are positively dangerous except in the hands of a physician. (2) "Reducing" foods containing laxative salts or cathartics remove water from the body—not fat. They too can be harmful. (3) Food concentrates or supplements to be taken with a reducing diet or exercise regimen are useless. It is the reduced energy content of the diet or the additional exercise that reduces weight—not the dietary supplement.

Iron, iodine, calcium, and other minerals to correct widespread "mineral deficiencies": Real mineral deficiencies can be corrected by a well-rounded diet. Mineral supplements should be used only on the recommendation of a doctor or trained nutritionist.

Vitamin products: The best and most economical sources of vitamins are ordinary foods. There is a legitimate place for vitamin concentrates, but not as cure-alls. Broad and indefinite claims for vitamin products should be distrusted.

Food fads: One of the commonest is that certain foods should never be combined with certain other foods—proteins with carbohydrates, for example, or acid fruits with starch. This is pseudo-scientific bunk. All kinds of combinations are made by nature in single foods. Claims made for partly digested or predigested foods, or "natural aids to digestion," are also questionable or unwarranted.

Panaceas for diseases: Among these are cures for "acid stomach"—all stomachs are normally acid or they could not digest food; "acidosis"—actually a rare condition of the blood, calling for medical treatment; constipation—for which there is no one cure, since there are different causes in different cases; and a long list of others, none of which can be cured by quack food or drug remedies.

THE WHITE RAT AS A CONTRIBUTOR TO SCIENCE

Ordinarily the rat is hunted down and exterminated as an enemy of mankind. But in one field it has been a benefactor of man. Experiments with rats have added enormously to our knowledge of what foods contain and what the various nutrients in foods do in the body. These experiments have pointed the way to the prevention and cure of many deficiency diseases and to a better understanding of the relation of food to health.

Not that the rat is unique. Other animals would do for nutritional experiments, and in fact other animals are used—the guinea pig, the rabbit, the pigeon, the chicken, the dog, for example. In fact, rats will not do for some experiments. The rat does not have a gall bladder, for example; it is immune to scurvy; and it does not need vitamin C in its diet. No one animal will do to represent the reactions of all animals, including human beings; nor can it be said positively that because one kind of animal reacts thus and so in a given experiment, other kinds of animals will react in the same manner; or because one kind of animal needs such and such an amount of a given nutrient, therefore another kind of animal needs a proportionate amount. All such conclusions must be tested directly on the other animal.

Nevertheless, the rat is typical of many animals, and its nutritional requirements have proved to be like those of human beings in so many ways that it is extremely useful. As the early physiologists discovered in many decades of difficult study, the fundamental bodily structure and functions of all mammals are very much the same.

The reason the rat is so extensively used in nutrition experiments is partly accidental. Rats happened to be used for some of the earliest experimental work that led to important discoveries in nutrition, and also for studies on the growth and development of the nervous system. A mass of useful data about the rat was collected, and it was natural for later experimenters to turn to the rat because these data were available.

But perhaps the most important reasons for the extensive use of the white rat are practical ones. The rat is small and handy; several hundred of the animals can be kept in comfort in a space the size of an ordinary living room. A rat can be fed for 50 cents a year as compared with $4.50 for a rabbit, $15 for a dog, $75 for a dairy cow, and $400 for an elephant. This is very important when it comes to using expensive purified foods. For example, it would cost $15 a day to feed protein to a rabbit in the form of pure amino acids, whereas it costs only $1.50 for a rat. (Even so, such experiments are expensive enough. The cost of amino acids in a recent experiment with a small number of rats was $50,000.) Just as important as economy is the fact that the rat lives very fast. Its life span is 2 to 3 years, so that 1 year is equivalent to 20 or 30 years in the life of a human being. It is possible to carry on an experiment with rats that will cover not only one generation but many successive generations. And more and more, in nutritional work, the scientist is seeking to discover the long-time effects of taking away or adding certain nutrients. It is as important to study these as to study the short-time effects that show up as acute symptoms.

HUMAN FOOD REQUIREMENTS CARBOHYDRATES, FATS, ENERGY

Carbohydrates

More than half of the average diet consists of carbohydrates. They are the sugars, starches, and indigestible fibers given to us by plants. The sugars and starches furnish energy (they are the preferred fuel for muscular work), and the indigestible material is useful to the body in other ways.

The sugars and starches are of three kinds, which may be classified in common language as single sugars, double sugars, and complex sugars—technically called monosaccharides, disaccharides, and polysaccharides. Only the single sugars can be absorbed into the blood stream and utilized by the body tissues. Hence all the other digestible carbohydrates must eventually be broken down to single sugars in the processes of digestion. The break-down is accomplished by enzymes.

Two single sugars, glucose and fructose (fruit sugar), occur naturally in fruits and vegetables, as well as being produced by the digestion of more complex carbohydrates in the body. The third single sugar, galactose, results when milk sugar (lactose) is broken down by digestion.

Three double sugars are commonly found in foods—cane or beet sugar (sucrose), malt sugar (maltose), and milk sugar (lactose). Sucrose, or ordinary granulated sugar, is the sweetest of these and is consumed in the greatest quantity—sometimes too much for health. Maltose is a manufactured product, made from starch through the action of enzymes in sprouting grain. It is also made in the human body when saliva acts on cooked starch, or the pancreatic juices on raw or cooked starch. Because of its easy digestibility, maltose is sometimes used for infants and invalids, although glucose in the form of corn sirup is the most commonly used sugar for infant feeding. Lactose occurs in milk. It digests slowly and when consumed in unusual amounts leaves an undigested residue that has a laxative effect. It also favors the growth of certain useful bacteria in the intestines, and there is evidence that it increases the absorption or availability of certain forms of calcium.

Starches, dextrins, and glycogen are the common digestible complex sugars. Starches occur in vegetables and fruits. Dextrins are made in the body in the process of digesting starch. Glycogen, sometimes called animal starch, is made in the body out of vegetable carbohydrates, and is the form in which these carbohydrates are stored in the liver and muscles, to be used as needed.

The indigestible carbohydrates mostly form the cell walls that are the structural framework of plants. Plant fibers furnish the bulk in the diet that is necessary for the normal muscular action (peristalsis) of the intestine. Agar-agar and pectin are two indigestible carbohydrates that have the property of absorbing a great deal of water and becoming jellylike in consistency. Agar-agar (from seaweed) is sometimes used to increase bulk in the intestine. Pectin, found in certain fruits and fruit seeds, apparently has the property of absorbing poisons or neutralizing certain harmful substances—hence the value of scraped raw apple in treating diarrhea and infant dysentery.

Research work carried on over many years shows that intricate processes are involved in transporting, storing, and utilizing carbohydrates in the body, and in maintaining a constant level of sugar in the blood. Recent work has concentrated on certain processes in which the endocrine glands and the nerves are involved. This includes work on diabetes, which may prove to be due not to a simple deficiency of insulin in the pancreas but to a maladjustment of several endocrine glands.

It is known that various nutritive elements, including thiamin (vitamin B_1) and riboflavin (vitamin G), play a part in carbohydrate metabolism. For example, dogs completely deprived of their pancreas have lived for 4 years on a diet rich in protein and vitamins. Much remains to be done, however, before we have a complete picture of what happens to carbohydrates in the body, in health or illness.

Fat

Fat is commonly thought of as a source of energy in the diet. A given weight of fat has more than twice the energy value of the same amount of carbohydrate or protein. Hence those who wish to reduce or to add weight should reduce or increase the fat content of the diet first. Fat also has "staying power" because it is digested rather slowly, and since it contributes much to flavor and texture in foods, the consumption of fat tends to increase with a higher standard of living.

Fats, however, do more than provide calories. They carry the fat-soluble vitamins, A, D, E, and K. Certain types of fat are essential parts of the tissues of the body; their unsaturated fatty acids are apparently necessary for good health. (A saturated fatty acid is one that contains all the hydrogen with which it can combine. It makes a fat that is usually solid at room temperature. An unsaturated fatty acid is one that could take on more hydrogen. It makes a fat that is usually liquid at room temperature.) Most common food fats—including the hardened vegetable fats—contain essential unsaturated fatty acids, and there is little danger that they will be lacking in an ordinary diet. Experimentally, however, a shortage can be produced with laboratory animals, and with rats it results in reduced growth and a skin disease.

Recent experimental work with fats in nutrition suggests that they may possibly help the body to use calcium under certain conditions; reduce the need for vitamin B_1; aid in the metabolism of milk sugar, and in the utilization of carotene by the body; and help to maintain a certain unsaturated fatty acid content of the blood which may be related to the occurrence of eczema in children. Most of this work is new and the results must be interpreted with care.

Energy

People of a certain age will remember the furor about calories early in this century. It was the beginning of the diet consciousness that has steadily increased ever since. Apparently the only thing that mattered about food in those days was whether you got enough calories—or too many, so that you became fat; and even today, undernourishment or starvation is still thought of as failure to get enough total food, or enough calories, to meet the energy needs of the body. People can starve to death, however, even when they eat too much food, if some element necessary to life is lacking in the food they get.

Calories are a measure of heat or energy. The energy stored in a given quantity of any food material can be measured rather accurately. The energy needed by the human body can also be measured accurately. The problem, then, is simply one of balancing the amount taken in with the amount needed, making due allowance for the waste in preparing and cooking food and the waste in digestion.

In everyday life, this balancing is done solely by observation, appetite, feeling. Normally, an adult who does not eat enough will get thin and run down; a child will fail to gain at a normal rate. If you eat too much, you will lay on weight. No fine calculations are needed, ordinarily, to find the happy medium in between.

Sometimes doctors, nutritionists, and others need to make these calculations. In many cases, the individual's food intake needs to be carefully prescribed. Diets are balanced on the basis of the calories furnished by different foods or different nutrients. Calorie counts are used in figuring the adequacy of the diets of individuals, families, groups, or even whole populations. In this work, lengthy tables of the calorie values of food are utilized, along with tables showing the calorie needs of individuals of different ages and sizes engaged in different kinds of activity.

The latter tables have been worked out largely from calorimetry studies. A calorimeter is an instrument for measuring the energy used by an individual, first for basal metabolism—the internal processes that go on even when the individual is completely at rest in a comfortable atmosphere—and then for any activity over and above this basic need. The basal requirement for an adult is about 1 calorie an hour for every 2.2 pounds (1 kilogram) of body weight. Here are some samples of the additional requirements per hour for different activities (for every 2.2 pounds of body weight): Sitting quietly, 0.4 calorie; standing relaxed, 0.5 calorie; walking, 2 calories; running, 7 calories; going upstairs, 14.7 calories; dishwashing, 1 calorie; sweeping, 1.4 calories; sawing wood, 5.7 calories; swimming, 7.9 calories. Curiously enough, the simple act of walking upstairs apparently requires more energy than the hardest work or the hardest sport carried on for the same length of time.

If it is known how much time an individual spends in various activities, it is possible to figure quite closely how much energy he or she will need to get from food during the day. Here are some sample figures of this kind: Average farmer's wife weighing 136 pounds, about 2,600 calories a day; average city housewife weighing 129 pounds, about 2,300 calories a day; average active farmer, about 3,500 to 4,000 calories a day; sedentary man of 154 pounds, about 2,400 calories a day; sedentary woman of 132 pounds, about 2,100 calories a day. Children need more calories per pound than adults, to meet the needs of growth. Nursing mothers need more. Old people need less.

Calorie requirements have been the subject of much thought, calculation, and research. The figures used by different nutritionists have not always agreed. In an attempt to reach a standard that could be agreed on everywhere, the Technical Committee on Nutrition of the League of Nations adopted a scale in 1935. According to this scale, "the average adult male or female living an ordinary everyday life in a temperate climate" needs 2,400 calories a day, or 100 calories an hour, for maintenance alone. To this must be added, for light work, up to 75 calories an hour; for moderate work, 75 to 150 calories an hour; for hard work, 150 to 300 calories an hour; for very hard work, 300 calories or more an hour. The nursing woman requires 3,000 calories a day for maintenance, plus the amounts given for various activities. Children are given the following allowances in calories a day for maintenance: 1 to 2 years, 840; 2 to 3 years, 1,000; 3 to 5 years, 1,200; 5 to 7 years, 1,440; 7 to 9 years, 1,680; 9 to 11 years 1,920; 11 to 12 years, 2,160; 12 years and over, 2,400. To these basic requirements, allowances are added for activity. The activities of children 5 to 11 years old are considered equivalent to light work, those of boys 11 to 15 years old as equivalent to heavy work, and those of girls 11 to 15 years old as equivalent to light work. Babies up to 6 months of age require about 45 calories a pound a day; those 6 to 12 months old, about 41 calories a pound a day.

PROTEIN REQUIREMENTS OF MAN

Since all living cells are made primarily out of protein it might truly be called the stuff of life. Nothing else can take its place in building new tissues in the body and replacing losses. But this is not its only function. Many of the enzymes and hormones in the body are either proteins or contain substances that make proteins. A very small quantity of protein in the form of an enzyme or hormone can have very powerful effects, much as the word of a commanding general controls an entire army.

There are innumerable kinds of protein; perhaps only a substance capable of such endless variety would fit the needs of living matter. All of them are made up of the simpler substances, amino acids. Some 22 amino acids are now known, and probably there are others undiscovered. As the letters of the alphabet combine to form words, these amino acids combine to form proteins; as different words combine to form sentences, the proteins in turn combine to form living tissues. A food is like a whole sentence. The words are taken apart in the digestive system and reduced to letters, or amino acids. The letters or amino acids are carried by the blood to all organs, all cells. Each cell or organ takes the particular letters it needs and rearranges them into new words or new proteins, which make new sentences.

Practically the whole alphabet of 22 amino acids is used to make the proteins that compose a human being. Some of them the body can apparently manufacture for itself, but there are at least 10 that it must get from food. If any of these is lacking, growth will not be normal or the processes of life will halt somewhere and somehow.

Many food proteins do not contain all these 10 amino acids, each one in adequate amounts for human needs. Hence the advisability, if not the necessity, of eating a variety of protein foods. Most protein foods contain several different kinds of protein, and a good mixture is like a whole paragraph of sentences; it will insure a supply of the right amino acids. Animal proteins—those in milk, eggs, glandular organs, lean meat—are especially rich in the necessary 10 that must come from food. It is advisable then to include a liberal supply of animal proteins in the diet, and an especially liberal supply in the diet of children, since children are building new tissue at a very rapid rate. Many of the vegetable proteins, even those in fairly protein-rich products like whole cereals and legumes, are notably low in one or more of the amino acids that human beings must get from food.

Partly because of this complicated amino acid situation, it is rather difficult to make general recommendations for the amount of protein an individual should have. A great deal depends on the amino acid make-up of the proteins eaten. Then, too, a fair amount of some proteins is not digested, especially if they are eaten uncooked.

A good many years ago the protein consumption of thousands of people in many countries was carefully studied. It varied considerably, but in general it was quite high. This was taken to mean that people ought to eat a lot of protein. Then it was found that though protein can be used as fuel by the body, it involves a good deal of waste; starch, sugar, and fat are burned up almost 100 percent as fuel in the body, but only part of a protein is burned and the rest is eliminated, mostly from the kidneys. Besides, protein is expensive con pared with starch and sugar. So there was then a wave of recon mendations for low-protein consumption—just enough, it was thougl to supply the need for body building and repair. Now the tende is to settle down between these two extremes—to recommend consi erably more than the very low figures, considerably less than the ve high ones. This is probably right, at least until there is a good dea more accurate evidence from the modern work with amino acids. A fairly liberal allowance of protein gives a margin of safety that may contribute to health and general well-being.

The Technical Commission of the Health Committee of the League of Nations recently recommended, in line with this trend, that an adult over 21 should get about 0.45 gram (about one-sixtieth of an ounce) of protein a day per pound of body weight. This is about 70 grams (a little less than 2½ ounces) for a 154-pound man, and about 60 grams (a little over 2.1 ounces) for a 132-pound woman. A pregnant woman should get half again as much as the adult allowance after the fourth month; a nursing woman, twice as much. The allowance per pound of body weight is greater at younger ages. At the age of 17 to 21 it is half again as much as that of the adult; at 15 to 17 years, twice as much; at 5 to 15 years, 2½ times as much; at 3 to 5 years, 3 times as much; and at 1 to 3 years, 3½ times as much. According to the recommendations, the protein should be derived from a variety of sources, and part of it should be of animal origin.

MINERAL NEEDS OF MAN

Calcium and Phosphorus Requirements

There is more calcium in the human body than any other mineral element. Ninety-nine percent of it is in the bones and teeth, and 1 percent circulates in the blood stream and permeates the soft tissues. But this 1 percent has very important functions in the blood, the muscles, the nerves. For example, the muscles that make the heart beat must be constantly bathed with blood or lymph containing a normal amount and proportion of calcium.

Calcium is rather abundant in nature, yet there is a calcium problem in nutrition because so many people no longer eat natural foods and because so many natural compounds of calcium are comparatively insoluble and therefore difficult for the body to use. One of the most common deficiencies in American diets, in fact, is a deficiency of calcium. In other words, it is necessary to use our brains to get enough calcium to build our backbones.

How much calcium should we try to get in our diet? This problem has been rather carefully studied over a period of 30 years.

It is possible to find the minimum needs of the body by balance experiments. After calcium has been used by the body it is excreted. Finding the lowest point at which the amount consumed will just balance the amount excreted from day to day should therefore show the minimum daily requirement of the body. In studies on a considerable number of adults over a considerable period of time, this minimum requirement ranged from 0.27 gram to 0.82 gram. The average of all the cases, by one method of interpretation, was 0.45

gram. Two other methods of interpretation gave higher averages, the highest being 0.55 gram. As a compromise between these extremes, 0.50 or one-half of a gram a day may be accepted as the average minimum requirement of the normal adult.

A margin of 50 percent must be added to this to allow for individual differences and the variations likely to be encountered in everyday foods. This makes a total of 0.75, or three-fourths, of a gram a day as the practical minimum—the figure now recommended by the League of Nations' Technical Commission on Nutrition.

But this is the minimum—not necessarily what is best for health. Experiments with hundreds of rats throughout the entire life cycle of several generations show that increasing the calcium allowance up to a point well over twice the minimum requirement results in positive gains in physical well-being. Long study makes it scientifically convincing that human beings would probably respond in the same way. On this basis, it is a conservative conclusion that for the best health, the calcium requirement of the normal adult should be set at not less than 1 gram a day. This is twice the actual minimum of one-half of a gram but only a third more than the practical minimum of three-fourths of a gram.

The Health Organisation of the League of Nations recommends that 1.5 grams a day be considered the requirement for pregnant and lactating women. This is to allow for the needs of the growing embryo and the nursing child. These needs will be met by calcium drawn from the mother's own body if she does not take an additional supply.

Though children are smaller than adults, they are growing and building bony structure that requires a relatively large amount of calcium. An extensive and intensive study of children 3 to 13 years of age indicates that their average requirement also should be set at 1 gram a day to provide for these needs and for individual differences. At least one investigator has recommended higher amounts for children of 15 to 16. The League of Nations' Technical Commission on Nutrition recommends 1 gram a day as the standard.

Phosphorus as well as calcium is necessary for the bones and teeth, but a much higher proportion of the phosphorus we consume is in the active tissues of the body rather than the bony structure, so that the daily turn-over is larger. It is not nearly so difficult, however, to get an adequate supply of phosphorus in the diet as to get an adequate supply of calcium.

Balance experiments indicate that the need for phosphorus is in proportion to body weight. The average minimum requirement has been determined as 0.88 gram for a 154-pound man or woman. Adding 50 percent as before gives a practical minimum requirement of 1.32 grams. This is generally accepted as the standard for adults. In the case of children, a recommended standard begins at 1 gram for boys under 8 and girls under 10 and increases gradually with increasing size up to the adult requirement.

Iron and Copper

The body of a healthy adult contains about one-tenth to one-seventh of an ounce of iron (3 to 4 grams). More than half of this is in the hemoglobin, or coloring matter of the red blood cells, where its function is to help in carrying oxygen to every cell of the body. Almost all the rest of the iron is in the liver, bone marrow, and spleen, waiting to be converted into hemoglobin as needed. Almost an ounce of hemoglobin is formed in the body every day to supply about a trillion new red blood cells.

This work requires more iron than the food supplies. The additional amount, over and above the food intake, comes from the daily destruction of old red blood cells. They give up their iron as they are destroyed, and it goes back to the bone marrow, which is a sort of hemoglobin factory, to be used again. However, the bone marrow cannot supply enough iron from broken-down red blood cells alone. When too little iron is taken in the diet, too little hemoglobin is manufactured, and the resulting disease is known as nutritional anemia. According to recent studies, a reserve supply of iron can be stored in the body if a generous amount is consumed in food.

Almost twice as much iron must be taken in the food as is actually required. This is because a considerable part of the iron in foods is tied up in chemical compounds that cannot be used by the body. To say that a food contains so much iron is meaningless from the nutritional standpoint. Analyses should show how much available iron it contains—iron that the body can use. For example, the iron in apricots, egg yolk, and calves' liver is 100-percent available; that in whole grains, 95; that in prunes, peas, and orange juice, 75; that in beef and lamb, only 25. Foods with a high content of available iron as well as a high content of total iron should be stressed in the diet when it is desirable to get a liberal amount of iron.

Again, individuals differ in their ability to utilize available iron and manufacture hemoglobin. In other words, some individuals need more iron than others to get the same results. There are also periods of unusual demand by the body and unusual losses. These factors make it advisable to get a generous supply constantly to furnish a margin of safety.

The infant is born with a store of iron in its liver. This is exhausted at about the age of 6 months. Milk has a relatively low content of iron, and unless additional amounts are supplied, anemia may develop then, or perhaps around the age of 2 years. Border-line nutritional anemia is fairly widespread among children 6 months to 2 years of age.

Apparently nutritional anemia seldom occurs in children 5 to 11 years of age. Adolescent girls, however, sometimes develop a disease known as chlorosis, which is now diagnosed as a form of anemia. Girls between 11 and 14 need a high intake of iron.

Getting enough iron is perhaps seldom a problem with men, and they rarely have anemia.

The situation is apparently different with women. The average hemoglobin content of the blood of women is about 10 percent less than that of men. But it is difficult to raise the hemoglobin content at all above the average in the case of men whereas it is easy to raise it considerably in the case of women. This suggests that women may be quite commonly abnormally low in hemoglobin. Women usually eat less food than men and would therefore get less iron. Their periodic functions are accompanied by a loss of hemoglobin. Anemia is more prevalent among women than men. Altogether, there are indications that women need more iron than men; one investigator believes they need four times as much. Pregnant and nursing women need additional amounts; anemia occurs frequently during the latter part of pregnancy.

Copper must be present with iron to form hemoglobin, although there is no copper in the hemoglobin itself. Most of the supply in the body is stored in the muscles, bones, and liver. In general, copper is found with iron in foods, so that there is little or no danger of a deficiency if the iron requirement is met.

The following daily allowances of iron and of copper are suggested as a result of metabolism studies:

Iron:	
Infant	0.36 milligram per pound of body weight.
Preschool child	0.27 milligram per pound of body weight.
Boys and girls 5 to 11 years	9-11 milligrams.
Boys over 11 years	13 milligrams.
Girls over 11 years	13–15 milligrams.
Man	12 15 milligrams.
Woman before menopause	17 milligrams.
Pregnant woman	20 milligrams.
Nursing woman	17–20 milligrams.
Woman after menopause	12-15 milligrams.
Copper:	
Infant	1–1.5 milligrams.
Child	1.5–2.5 milligrams.
Adult	3.5 milligrams.
Pregnant or nursing woman	3.5–4 milligrams.

Iodine and Fluorine

The thyroid gland contains a substance, thyroxin, which has powerful effects in regulating growth and the use of energy by the body. Iodine is a necessary element in thyroxin. Very little iodine is needed, but failure to get enough results in the disease known as simple goiter. Human beings get their supply of iodine from food products, which in turn have obtained it from soil or water. Sea foods are all rich in iodine.

There is a considerable "goiter belt" in the United States where the soil and water are low in iodine. It stretches along the Appalachian Mountains to Vermont, through the Great Lakes Basin to the State of Washington, and southward over the Rocky Mountains and Pacific States. Preventing goiter in this region is a problem of supplying iodine in other ways than through food locally produced. Foods known to be rich in iodine may be used, or iodine may be added to the diet through the use of iodized salt— 1 part of iodine to 100,000 parts of salt. The danger of ill effects from the latter method may be minimized by limiting the use of the salt to the first 20 to 30 years of life and periods of pregnancy and lactation. Methods are under investigation for adding iodine to the food supply by way of fertilizers for the soil and iodine-rich foods for dairy cows and hens, which would increase the amount in milk and eggs.

Fluorine is poisonous to human beings in very small amounts. It affects the teeth, producing mottled enamel and structural weakness. The amounts ordinarily received in foods are not harmful, but in certain areas in 20 States in the West and Middle West, and in several foreign countries, the water supply contains enough to be harmful. The effects are especially bad during the period of tooth formation, from birth to 12 years of age. An effective method for removing fluorine from water by filtering through ground bone has recently been developed by the Arizona Agricultural Experiment Station. It is based on the fact that fluorine has an affinity for bone calcium, with which it readily combines.

Trace Elements

Certain minerals and other inorganic substances are commonly called trace elements because they are found, in the body or in food, in very minute amounts, mere traces. With the ordinary chemical methods of analysis, the presence of many of them was never suspected. They were revealed by the spectrograph, an instrument used to show what the stars contain and to detect slight impurities in metals. Then it turned out that some of these trace elements in soils, in plants, in animal bodies, and in the human body, play an extremely important part in life processes. Without a little of some of them, animals and plants become diseased or die. But a little too much may also be fatal. Investigations in this field are only beginning. They have revealed tantalizing glimpses, fragments of facts, like a mystery story half told. The trace elements will be listed here with brief comments.

Manganese: Found principally in the liver, pancreas, and the small glands (suprarenals) just above the kidneys. Rats deprived of manganese fail to reproduce normally; chickens have deformed leg bones (perosis). Apparently a little is necessary in the diet, but too much is poisonous.

Cobalt: Found in most of the organs of the human body. . Increases the number of red corpuscles in the blood. Sheep suffering from the deadly "coast disease" in New Zealand and Australia are cured by cobalt sulfate—an ounce a day for 4,000 animals.

Aluminum: Generally distributed in the body. No one knows whether it is necessary or not. The average person gets about 1 ounce in 6 years from food and cooking utensils. Not harmful in the amounts normally consumed.

Magnesium: Apparently necessary for normal development. Experimental animals deprived of it get convulsions and die.

Zinc: Always present in human tissues, especially the sex organs and thyroid gland. Considerable amounts are stored in the liver of infants and in colostrum milk. Apparently necessary for normal development.

Tin: Found in many body tissues, especially the suprarenal glands, liver, brain, spleen, thyroid gland, and mucous membrane of the tongue. Apparently no harmful effects from amounts ordinarily consumed.

Arsenic: Found in most body tissues, especially the liver. The amount in the blood increases in pregnancy and in cancer. Perhaps traces are essential in human nutrition.

Vanadium: Found in some foods. Not poisonous to experimental animals in relatively high concentrations.

Selenium: Causes the fatal "alkali disease" of cattle in certain parts of the West where it is concentrated in the soil and in some range plants. Effects on human beings unknown.

Bromine: Occurs normally in the blood; concentrated in the pituitary gland. Only half the normal amount is found in the blood of those suffering from a certain type of insanity (manic-depressive psychosis).

Boron: Found universally in plants and probably significant in human nutrition.

Nickel: Widely distributed in human tissues, especially the pancreas.

Alkali metals: Caesium and lithium are occasionally found in animal tissues. Rubidium is widespread in the body, especially the liver. Unusually large amounts are found in the livers of infants dying from a certain constriction of the small intestine present at birth (congenital pyloric stenosis). Perhaps rubidium is necessary for muscle growth.

Barium, strontium, beryllium: Barium is always present in the eyes of cattle. Both it and strontium are occasionally found in human tissues. Excessive amounts of beryllium produce severe rickets in experimental animals.

Silver, gold: Silver is most concentrated in the thyroid gland and tonsils; reported also in blood, liver, uterus, ovaries, heart, spleen, kidney. The presence of gold in human tissue has not been demonstrated.

Cadmium, mercury: Mercury has been found in human liver and in a number of foods. Cadmium has not been reported in human tissues.

Silicon, germanium, lead: Silicon is found in human tissues; causes a disease, silicosis, among workers inhaling large quantities. Germanium is reported in blood—stimulates the manufacture of red blood cells. Lead is fairly widespread in tissues; excessive quantities cause lead poisoning.

Other trace elements about which even less is known include titanium, zirconium, cerium, thorium, antimony, bismuth, chromium, molybdenum.

VITAMIN NEEDS OF MAN

Vitamin A

Most people think of vitamin A as a yellow substance found in carrots, in green plants, and in certain animal products, including milk and fish-liver oil. Actually, however, plants do not contain any vitamin A. They do contain certain yellow materials—the carotenes and related substances—that can be converted into the nearly colorless vitamin A in the bodies of animals.

When you eat carrots, then, you get no vitamin A; you get vitamin A "value" or vitamin A "potency" in the form of carotene that your body can use to make vitamin A. When you drink milk, you get vitamin A and also, usually, some carotene that has not yet been converted into vitamin A. When you eat egg yolk, you get some vitamin A and some yellow cryptoxanthin—related to carotene— which can be converted into vitamin A.

Within the animal body, the liver is the great storehouse for reserve supplies of vitamin A—hence the value of oils extracted from the livers of fish. In plants, intense green color—as well as intense yellow—is usually a sign of high carotene content. Egg yolks, cream, and butter, on the other hand, may be very pale in color yet high in vitamin A itself as distinct from carotene.

When animals are completely deprived of vitamin A, they cannot live very long after their own bodily reserves are used up. Short of complete deprivation, an inadequate supply plays havoc with the animal or human body. First the eyes are affected; they are unable to see well or perhaps to see at all in dim light—a condition known as night blindness, which, incidentally, may be disastrous to anyone who drives an automobile. Next, in more severe cases, comes extreme muscular weakness and changes in the epithelial or surface or skin cells, which become unable to function properly. These cells cover every surface of the body, outside and inside, including the nose, throat, lungs, and the other internal cavities and organs. They are the body's first line of defense against injury or against invasion by disease organisms; and when they are damaged, this defense is broken down. Finally, very acute stages of deficiency lead to xerophthalmia—a serious eye disease that may cause complete and permanent blindness.

There is a popular belief that vitamin A prevents infection—colds, for example. This is not the present medical view. If the body is deficient in vitamin A, however, its resistance to infection is lowered. But if the body has a good store of vitamin A and the food supplies liberal amounts of this vitamin, a lot more vitamin A will not increase resistance to infection.

The Bureau of Home Economics has been working with one of the newer methods for finding out how much vitamin A people need. It depends on the fact that the eyes are quite sensitive to lack of the vitamin. The subject looks into a device called a visual adaptometer, which first exposes his eyes to a bright light, then to darkness, then to a dim light. By varying the intensity of the dim light, the adaptability of the eyes can be measured. Several people have served as voluntary guinea pigs in this work, eating a diet in which the amount of vitamin A is accurately measured and rigidly controlled. It developed that some subjects needed twice as much vitamin A as others—a difference greater than can be accounted for by differences in bodily size. Also, carotene was not as efficiently utilized as vitamin A itself.

The average daily requirement of adults for vitamin A and carotene together is about 3,500 to 4,000 International Units. With a margin of safety of about 50 percent, it is estimated that an adult should eat foods that will supply 5,000 to 6,000 International Units of vitamin A daily. The best available information indicates that vitamin A needs can be met by using such combinations of foods as these daily:

Infants—small doses of cod-liver oil, beginning at a very early age.

Children 2 to 14 years—about 1 quart of whole milk; an egg or egg yolk; butter; green, leafy vegetables; a half teaspoonful of cod-liver oil.

Adults—a pint of whole milk; an egg; two pats of butter; one serving of a leafy green or yellow vegetable.

Pregnant or nursing women—a quart of whole milk; an egg; one serving of a leafy green or a yellow vegetable; 1 teaspoonful of cod-liver oil.

Vitamin B_1

In the early days of vitamin research nutritionists interpreted their experiments to prove the existence of a factor in foods which they named "vitamin B." It was gradually demonstrated that this substance was really a group of vitamins, like a lump of ore containing several minerals. So far they have isolated and synthesized vitamin B_1; vitamin B_2 or G, now called riboflavin; nicotinic acid; and vitamin B_6. The presence of still other factors in this complex group of water-soluble vitamins has been indicated. Our knowledge of the need for these substances in human nutrition is rapidly progressing.

Vitamin B_1 was first synthesized in the laboratory in 1936 and given the chemical name "thiamin chloride." It is a crystalline substance easily soluble in water and destroyed by heat. When present in foods it may be lost to some extent in the cooking process, owing to the effect of heating and to loss when the cooking water is discarded.

The vitamin is widely distributed in foodstuffs because every living cell, plant or animal, apparently has to have some thiamin chloride. It combines with phosphoric acid to form a substance that plays a vital part in the process of releasing the energy stored up by the sun in carbohydrate foods. The vitamin, as it is manufactured by the plants, is stored in the seed, doubtless to be ready for use when growth begins.

The characteristic disease resulting from vitamin B_1 deficiency is beriberi. Among the early symptoms of beriberi are loss of appetite, nervousness, fatigue, stiffness. Later, the functioning of the heart may be affected; in wet beriberi the tissues swell up; in dry beriberi there are changes characteristic of a chronic form of the disease; in acute pernicious beriberi there is enlargement of the heart. The nervous disturbance—or polyneuritis associated with beriberi may result in loss of control of the muscles and in uncoordinated, jerky muscular contractions. When beriberi is not acute, the symptoms may be vague and hard to define. Again, beriberi may be complicated by other nutritional deficiency diseases, since lack of vitamin B_1 affects the appetite and can easily cause a reduced consumption of several essential things in the diet.

One of the landmarks in the history of modern nutritional science was the curing of an outbreak of beriberi in the Japanese Navy in 1883. These sailors were living on a diet of polished rice and dried fish. When they were fed meat, vegetables, and milk in addition, there was no more beriberi. Later, it was found that the part of the rice that was thrown away—the outer coat and the germ—contained the substance that would have prevented beriberi in the first place. Rice polishings, wheat germ, and yeast are all potent sources of vitamin B_1.

As with all deficiency diseases, beriberi can be prevented and cured by a well-balanced diet. The amount of vitamin B_1 an individual requires is associated with the amount of energy he uses—or more strictly, the amount he uses from carbohydrate and protein foods, since thiamin chloride is tied up with the utilization of energy from these foods by the body cells. There is little agreement on the amounts of the vitamin necessary for the best of health, and some uncertainty about even the minimum requirements. The experimental use of pure crystalline vitamin B_1 will doubtless help to clear up the problem. Meanwhile, the following daily requirements are suggested from present evidence:

Infants—not known; it has been estimated that infants under 6 months normally obtain not more than 50 International Units of vitamin B_1 daily from mother's milk.

Children—same range as adults, depending on the amount of carbohydrate food utilized, which in turn depends on body weight and activity.

Adults—135 to 450 International Units, depending on energy utilization (more liberal estimates run as high as 700 International Units).

Pregnant and lactating women—600 to 700 International Units, or 20 International Units per 100 calories of food consumed. (Fatal cases of infantile beriberi have been known to result from an inadequate supply of vitamin B_1 in the milk of mothers on a very deficient diet.)

Clinical conditions—an increased supply is probably needed as a result of high fever, an overactive thyroid gland, and diseases involving a large loss of water such as diuresis and diarrhea.

Vitamin C

That there is something in citrus fruits and green vegetables that prevents scurvy has long been known; sailors were called limeys in England because on long voyages they sucked the juice from limes to avoid the scurvy resulting from a limited diet. Modern nutritionists named this scurvy-preventing substance vitamin C. It was first synthesized in the laboratory in 1933 and now has the chemical name of ascorbic acid—equivalent to antiscurvy acid.

Research workers in nutrition keep getting a little closer to an understanding of the part played by vitamins in fundamental body processes. The picture is very incomplete as yet, but it is slowly being pieced together, and some day it will be a fascinating panorama of life. In the case of vitamin C, the picture shows that certain cells in the bones and teeth and elsewhere are surrounded by a firm jellylike or cementlike substance, and that when the body is deprived of the vitamin, this substance becomes thin and watery. It is no longer effective in holding the cells in place. Housewives will be reminded of the function of pectin in jelly making. Ascorbic acid seems to act something like that in the body.

It is also an oxidizing-reducing agent—that is, it readily combines with either oxygen or hydrogen—and this may be important in its body functions, perhaps accounting for the fact that it is necessary for the proper functioning of a substance in the blood (the blood-serum complement) that acts as a primary defense against infections. After ascorbic acid has taken on a load of oxygen, it is no longer active. This means that it can easily be destroyed or damaged by exposure to the air.

Some animals—among them poultry, swine, and cattle—manufacture their own vitamin C. Others, including man, monkeys, and guinea pigs, must get it in their food. When they do not, several things happen. Diseases that would otherwise be resisted become dangerous; the walls of small blood vessels are weakened and break easily, producing small hemorrhages, called petechiae, under the skin; joints stiffen and feel sore; gums swell and bleed, and teeth loosen; wounds heal with difficulty, even when they are not infected.

These are symptoms of a severe shortage of vitamin C. A milder deficiency may affect health without any very obvious outward signs. The general lassitude sometimes called spring fever, for example, may be a result of vitamin C deficiency. Continued, unaccountable restlessness and irritability in infants and young children may be a sign of deficiency.

Earlier knowledge of vitamin C requirements came from guinea pig experiments. Within the past 8 years, work has been done directly with human beings. Three methods are used.

(1) An instrument that puts the blood under pressure is applied to the upper arm. If petechiae appear, the subject may be suffering from a shortage of vitamin C. The amount that will just prevent these tiny hemorrhages can be determined. But it is a minimum requirement. It takes a rather severe shortage, such as may occur in diets in northern countries in the winter, to produce petechiae.

(2) The amount of ascorbic acid excreted in the urine of a subject is measured. The difference between this and the amount taken in the diet presumably measures what is used by the body (though not exactly; there are unaccountable losses). The amount that will just keep the body in equilibrium, with the intake equaling the outgo, can be determined. But this too is a minimum requirement.

This method can also be used to measure what may be an optimum requirement, or the amount most favorable to health. The urinary excretion of vitamin C is measured before and after very large test doses of the vitamin have been given. Not until the body is completely saturated with all the vitamin C it can hold will there be a sudden large increase in the amount appearing in the urine after a test dose. Some authorities think this saturation point represents the body's optimum requirement. In the case of a guinea pig, saturation is not reached until the animal is consuming all the green food it will naturally eat on a freely chosen diet.

(3) The vitamin C content of the blood is measured while the subject is in a fasting condition. Within limits, this indicates the vitamin C status of the body as a result of the diet before fasting.

From these tests and other data, tentative standards for human vitamin C requirements have been worked out, though it must be said that there is no universal agreement about optimum allowances as yet. Considerable evidence also exists indicating that exceptionally large amounts of vitamin C are needed in certain clinical conditions—for example, gingivitis (bleeding gums) and pyorrhea, stomach ulcers, wounds, rheumatic fever, pulmonary tuberculosis, diphtheria, pneumonia. Does vitamin C play a part in preventing as well as curing some of the infectious diseases? There is growing evidence that it does, though just how no one knows.

The suggested requirements given below are in terms of milligrams of ascorbic acid. One teaspoonful of orange juice contains about 2½ milligrams of the pure vitamin; 1 tablespoonful, about 7½ milligrams; 1 fluid ounce, about 12½ milligrams; ½ cupful (4 fluid ounces), about 50 milligrams; 1 cupful (8 fluid ounces), about 100 milligrams. Grapefruit juice and lemon juice have about the same vitamin C content as orange juice; tomato juice has about half as much; pineapple juice a fourth to a third as much. There are other fruits, and many vegetables, that are good sources of vitamin C.

Infants, from birth to 9 months—minimum, 10 milligrams; suggested optimum, 50 milligrams. (These figures are based partly on the amounts normally received by infants from breast milk with a high vitamin C content. In many cases, breast milk is low in vitamin C. There is often need to give additional vitamin C while the infant is nursing.)

Children, 9 months to 6 years—minimum, beginning with 10 milligrams, increasing gradually to 20 milligrams; suggested optimum, beginning with about 50 milligrams, increasing gradually to about 100 milligrams.

Older children—no data available; the amounts for adults are suggested.

Adults—minimum, 28–30 milligrams; suggested optimum, 100 milligrams or more.

Pregnant and lactating women—minimum, at least 80 milligrams.

Elderly people—minimum, 50 milligrams. (This is more than the minimum suggested for younger adults. There is evidence that elderly people cannot become adjusted to a shortage so well as younger people.)

Vitamin D

Sterols are organic compounds that occur in all natural foods. When certain sterols are exposed to ultraviolet light, they become vitamin D; and the vitamin D in some way helps the body to use calcium and phosphorus, which make bones and teeth. (There must be enough calcium and phosphorus, of course, for the vitamin to work with.)

When a human being receives enough exposure to sunlight, then, he needs no vitamin D except what is formed by the sun from the sterols in his skin. He may even store up a reserve as a result of exposure during the summer. But with modern indoor living and smoky atmospheres, not enough ultraviolet light may reach the skin to create sufficient vitamin D. Then it is necessary to supplement the body's natural supply. A commonly used supplement is fish-liver oil.

A shortage of vitamin D or of calcium and phosphorus in infancy and early childhood means that the soft cartilaginous bone will not be converted into firm hard bone, and the bony framework of the body will not grow properly. The condition that results is called rickets—a disease that has been quite widespread in this country in the past, and that is still an ever-present menace.

Most of the work on human vitamin D requirements has been done with infants and young children because there is no adequate criterion of deficiency in older children or adults. There is some evidence to indicate that a considerable amount is needed to prevent decay of the teeth in older children and adolescents, especially during the winter and spring. Some authorities believe that adults do not require any vitamin D in their diet except in the case of pregnant and lactating women, who must supply the needs of a new body.

Legal standards for the vitamin D content of cod-liver oil require that 1 teaspoonful shall contain 312 U. S. P. (United States Pharmacopoeia) units as a minimum. It is possible to take too much vitamin D. According to the best knowledge now available, the daily vitamin D requirements in U. S. P. units, for individuals of various ages, are:

	U. S. P. Units
Infants:	
Artificially fed	300-800
Breast-fed	300-400
Premature	600-800
Children and adolescents	300-800
Adults	Unknown.
Pregnant and lactating women	300-800

Vitamin E

About 15 years ago it was found that rats failed to reproduce unless there was a substance that was named vitamin E in their diet. The female conceived, and the fetus grew to a certain stage of development; then it was usually resorbed in the uterus. The males failed to produce living spermatozoa, and there were changes in the tissues of the testes. Goats, however, have reproduced successfully for five generations on diets apparently completely free of vitamin E.

There is no certain evidence that human beings need this vitamin. Studies indicate definitely that wheat-germ oil—a rich source of the vitamin—is of no value in treating sterility. Reports published in Europe indicate that it was beneficial in about three-fourths of the cases of habitual abortion treated. Habitual abortion is repeated abortion in the early stages of pregnancy. It is not of common occurrence.

Vitamin E occurs widely in common foods, and a deficiency would not be likely to occur.

Vitamin G (Riboflavin)

Vitamin G or B_2 is one of the compounds found in the original vitamin B complex. It has now been identified as a crystalline substance containing a sugar (*d*-ribose) and a yellow coloring matter (flavin), and it has been given the chemical name riboflavin. It was first produced synthetically in the laboratory in 1935.

Like vitamin B_1, riboflavin apparently combines with phosphoric acid and a protein to form an enzyme, which is said to be present in every living cell and is concerned with oxidation—the burning of fuel for living processes. It is therefore of fundamental importance. It is most abundant in organs in which rapid chemical changes take place—liver, kidney, heart, germ of the seed, green leaves—though it is found in greater or less abundance in many common foods, including milk, eggs, meat, fruits, vegetables, and grains.

When rats are deprived of riboflavin, their hair falls out, their skin becomes inflamed and swollen (dermatosis), the tips of their toes drop off. According to a recent description, a severe deficiency in man also produces an inflamed and scaly condition of the skin around the corners of the mouth, the base of the nose, and the ears.

Work by Sherman with rats indicates that a very liberal allowance of riboflavin over the amount necessary to prevent the first sign of deficiency is worth while in terms of increased healthfulness. Probably any well-balanced diet including a large variety of unrefined foods would provide a liberal allowance for human beings.

The Pellagra-Preventive Factor

The substance that prevents and cures blacktongue in dogs and pellagra in humans was first chemically isolated in 1937, and was found to be nicotinic acid amide. In the body, this substance functions as a part of an enzyme, necessary in the fundamental life processes whereby energy is released from food for use by the body. For this function, nicotinic acid combines with phosphoric acid, a purine, and a sugar.

That the diets of pellagrins are deficient primarily in this substance, nicotinic acid, was discovered in the search for a cure for blacktongue in dogs, a disease so much like human pellagra that what will cure one will cure the other.

Pellagra is primarily a disease of ill-fed people. Thirty percent of the population of Egypt have been known to be affected; 400,000 cases annually have been reported in the United States; 10 percent of the inmates of asylums in the South have been mentally affected as a result of pellagra.

The disease affects the skin as symmetrical areas that become red, roughened, scaly, and horny. It affects the digestive system; the tongue and the linings of the mouth and throat are inflamed; then the tongue and the linings of the mouth and the stomach become swollen and ulcerated; there may be a lack of hydrochloric acid in the stomach, and severe diarrhea. It affects the nervous system; there is nervousness, dizziness, headache, numbness or paralysis of the extremities, degeneration of the spinal cord, loss of coordination, mental depression, and finally hallucination, delirium, and insanity.

This is the result of an inadequate diet, whether it is corn pone, sirup, and sowbelly or some other combination used by the ill-fed. These diets are deficient in nicotinic acid; the effects of administering this substance are dramatic and evident in a few days. The real preventive, however, is an all-round good diet. Because the diet that causes pellagra is a very poor one, other deficiencies than nicotinic acid- notably vitamin B_1 and riboflavin—are likely to be involved, and the disease is commonly complicated by these other deficiencies.

Human requirements for nicotinic acid are not known with any certainty. Foods that have high pellagra-preventive value, according to the studies made by Goldberger and his associates of the United States Public Health Service, who did pioneer work in this field, are yeast, milk, wheat germ, lean meats, liver, tomato juice, green vegetables, peas, and peanut meal.

FOOD COMPOSITION

Tables showing the composition of foods, painstakingly compiled from the results of hundreds of separate analyses made in many scattered laboratories, are the basis for all dietary calculations. With these tables it is possible to plan diets that will meet certain nutritional standards, or to analyze the diets that people are actually using. Some tables show proximate, or approximate, composition—that is the amounts of water, protein, carbohydrate, fat, and total minerals in foods. Others deal with separate minerals and still others with vitamins.

The first extensive tables of proximate composition were made by Atwater and Bryant in 1896. They are still used, along with others more recently prepared. New tables that bring the material up to date and include many foods not formerly listed are ready for publication by the Department of Agriculture.

In making analyses for proximate composition, the amount of water is determined by accurately weighing the material before and after drying, to see how much water it loses. Protein is determined by first finding how much nitrogen the food contains. This is multiplied by a certain figure—usually 6.25, since nitrogen is about 16 percent of most proteins—which gives a working estimate of the total amount of protein present. (It is necessary to go through a much more elaborate analysis to determine what kinds of protein a food contains.) Fat is determined by dissolving it out of the food with ether—hence fat is sometimes referred to as "ether extract." Total minerals are determined by burning the food completely and weighing the ash, since minerals are not destroyed by burning. Minerals are therefore often referred to as "ash." Carbohydrate is determined by figuring what is left over after these four other substances are determined—hence it is sometimes called "total carbohydrate by difference." Some analyses, however, break down the carbohydrates into sugars, starches, and crude fiber.

Obviously some of these methods give results that are not strictly accurate. There are other sources of error in food tables. For example, the amount of certain minerals differs in different varieties of some fruits and vegetables, or at different stages of maturity; the amount of calcium in green cabbages is much greater than in white, for instance. Or the total amount of a mineral may not tell at all how much is available for use by the body. For example, in some vegetables calcium becomes tied up in an unusable compound with oxalic acid, and in iron-rich foods some of the iron may be in forms that cannot be used.

For these and other reasons, food-composition tables leave much to be desired from the standpoint of complete accuracy. In most cases this does not seriously interfere with their usefulness because of the large quantities of different foods eaten by the average individual over a considerable period of time, which tends to iron out minor errors. New or more refined analytical methods are needed in some instances, however, and food-composition data in general would benefit if more analyses were made with the nutritionist's needs in mind.

Existing data on the quantities of calcium, phosphorus, and iron in foods are by no means so complete as those on moisture, protein, carbohydrate, fat, and ash, and in many cases they are relatively crude approximations. They give enough information, however, to indicate what foods are excellent or good sources of each of these minerals, to determine in general whether a given diet is too low in any one of them, and to plan diets with safe allowances. Lists of foods rich in calcium, phosphorus, and iron are given in the article on Food Composition.

No summary of the analyses of other minerals has been made by the Department of Agriculture, partly because the data are very meager, partly because most of these minerals occur so commonly in foods that dietary deficiencies in any one of them, so far as human beings are concerned, probably occur only under special conditions. These minerals include sodium, potassium, magnesium, copper, cobalt, manganese, zinc, arsenic, sulfur, chlorine, iodine, and bromine.

VITAMIN CONTENT OF FOODS

The existence of the vitamins has been known for only 25 years or so, and only within the last few years has it been possible to see or touch any of them in a pure form; previous to that they were mysterious invisible things known only by their effects. Practically all of the analysis of the vitamin content of foods was carried out while they were still mysterious and invisible, when the only way to measure them was by their results in promoting growth or in curing certain disease conditions in animals—a most difficult and tedious method. It is not surprising, then, that measurement of the vitamin content of foods has been somewhat uncertain, though it is rapidly improving today. A considerable amount of information has been collected, however, and at least it is possible to say in most cases whether a certain food is an excellent, good, fair, or poor source of any one of the better known vitamins. This is frequently enough for practical purposes, though the professional nutritionist needs to know actual quantities.

Lists of the more common foods that are good sources of vitamins A, B_1 (thiamin), C (ascorbic acid), D, G (riboflavin), and nicotinic acid (which is apparently the anti-pellagra substance) are given in the article on Vitamin Content of Foods. In general, it may be said that yellow-colored and green-colored vegetables and fruits are rich sources of carotene, which becomes vitamin A in the animal body, and that liver, egg yolk, butter, cheese, and fish-liver oils are rich in vitamin A itself.

Very few foods except fish-liver oils, egg yolk, and some fish naturally contain much vitamin D, though it is now put into some foods in two or three different ways.

Citrus fruits and tomatoes are commonly thought of as the outstanding sources of vitamin C, but a good many fruits and vegetables contain considerable quantities, and it is quite possible to make up for the lack of citrus fruits and tomatoes by good meal planning.

The richest sources of thiamin are whole-grain products, pork, chicken, kidney, liver, green peas and green lima beans, peanuts, and dried peas and beans, but a considerable number of vegetables, fruits, and nuts are fair sources.

Milk, eggs, meat, green leafy vegetables, whole cereals, and legumes all furnish liberal quantities of riboflavin.

The foods that contain nicotinic acid in liberal amounts are in general lean meats, chicken, liver, milk, buttermilk, and certain green leafy vegetables and legumes. Tomato juice is also listed among the foods useful in treating pellagra.

Different varieties of the same fruit or vegetable vary in vitamin content, which is also affected in some cases by maturity, and in the case of animal products, by feeding practices. Storage quite commonly results in some loss of certain vitamins, and so do some methods of processing. Finally, cooking may be responsible for considerable losses unless care is taken to preserve the vitamin values. A few of the more important precautions the housewife can take are:

Not to stir air into foods while cooking; not to sieve them while hot; not to use soda in cooking green vegetables; not to use long cooking processes when shorter ones are possible; not to fry foods valuable for vitamins B_1 or C; not to use the open-kettle method for canning and preserving; and on the positive side—use as little water as possible; bring foods to the boiling point quickly; use the cooking water for soups, sauces, and gravies; prepare chopped fruit and vegetable salads just before serving; begin cooking frozen foods while they are still frozen; serve raw frozen foods immediately after thawing.

PRESENT-DAY DIETS IN THE UNITED STATES

From the practical standpoint, all of the modern work in human nutrition may be summed up as an attempt to answer three questions: What do we need in order to be well nourished? Do we get what we need? If not, how can we get it?

A clearer answer than we have yet had to the second question—do we get what we need to be well nourished? can be found in two recent extensive surveys of the food-consumption habits of American families.

In a nutshell, this answer is that all too many families in the United States have poor diets; some have fair or passable diets; and only relatively few have really good diets.

All such surveys are based on samples of the population. These surveys covered various regions throughout the country. None of the families included were on relief. One study represented various income levels, from low to high, and took in native-born groups on farms, in villages, and in small and large cities. The other included families of employed workers in cities only. There is every reason to believe that each sample of families was fairly representative of the population group studied.

The standards for rating the diets as good, poor, or fair were based on the best information available from many sources. They can probably be considered conservative. Eight nutrients vital to health were included in these standards protein, calcium, phosphorus, iron, vitamin A, vitamin B_1 (thiamin), vitamin C (ascorbic acid), and vitamin G (riboflavin).

To be rated as good, a diet had to contain not less than a certain definite quantity of each of these nutrients—not so large a quantity, incidentally, as some nutritionists advocate for a top diet. A diet was rated as fair if it contained not less than a certain minimum of each of the nutrients—a minimum considered necessary to escape real nutritional dangers. A diet with less than this minimum of one or more nutritive elements was rated as poor.

In estimating the nutritional needs of a family, the age, sex, and degree of activity of individuals were taken into account. The quantities of the nutrients in the foods consumed were computed from standard tables used by nutritionists.

Farm families made a somewhat better showing, on the whole, than city and village families. Nutritionally, the difference between a good or fair diet and a poor diet appears to be related to the quantities of protective foods consumed—milk, eggs, vegetables, fruits. Farm families in general had more of these foods because they are so commonly produced on the farm for home use. Even so, farm diets frequently failed to include enough fruits and vegetables. Village families fared worst, perhaps because they neither produce for home use nor have large city markets available.

A common cause of failure among city and village families to get enough protective foods is a lean pocketbook—at least so far as low expenditure for food is a sign of a lean pocketbook. For example, in North Atlantic cities, families spending $4 a person a week for food bought five times as much citrus fruit and three times as much of the leafy, green, and yellow vegetables as those spending $1.60 a person. In general, purchases of milk, butter, eggs, meats, and succulent vegetables went up as food expenditures increased.

On the other hand, the reason for poor diets is by no means entirely economic. For example, there were enough actual cases to prove that a diet rated good could be bought by city and village families for as little as $2.50 a person a week. Some 65 percent of the city and village families surveyed were spending at least this much, but not many of them bought really good diets.

It is perhaps fair to assume that if something over 3 out of 10 city and village families spend too little to get a really good diet, another equally large group fails because families do not know enough about nutrition or are not good enough managers to get anything but a poor or fair diet.

But in defense of the housewife it should be added that it is a more discouraging job, and it takes more wisdom and ingenuity, to get a good diet when expenditures must be quite limited than when they can be generous.

Certain regional and other differences were brought out by the survey. For example, families in Pacific coast cities use more citrus fruits, succulent vegetables, and milk (even so, only a pint a person, children included) than any other group studied. Southern Negroes use more fish, pork fat, and watermelons than anyone else.

Long-time trends in food consumption in the United States show increases in the use of certain protective foods, notably citrus fruits (a phenomenal rise), milk, and some of the vegetables. The consumption of meat has declined somewhat. Among foods notable as cheap sources of food energy, the consumption of sugar has increased and that of grain products and potatoes has decreased.

PLANNING FOR GOOD NUTRITION

Anyone could easily arrange a good diet if it were possible to tell by looking at, tasting, or smelling a food what vitamins, minerals, and other nutrients it contains, and how much. Since this is not remotely possible, the average person bent on achieving good nutrition must either figure out a diet from elaborate food-composition tables, or accept the recommendations of reputable nutritionists. And the nutritionists have their own troubles trying to put what they know into practical terms that almost anyone can use in planning daily meals. Unless that can be done, research in nutrition is more or less academic.

One of the most useful methods so far devised is the four-diets plan worked out by the Bureau of Home Economics. The central idea in this method is that practically all of the scores or hundreds of foods people eat can be divided into a dozen broad groups, each of which makes some major contribution to our needs. In arranging a diet, it usually does not matter much what particular foods we choose from each group, so long as we keep the right combination of groups in the right amounts; and these combinations and amounts are given in the diet recommendations. Twelve major groups are used: (1) Milk and milk products; (2) potatoes and sweetpotatoes; (3) dry, mature beans, peas, and nuts; (4) tomatoes and citrus fruits; (5) leafy, green, and yellow vegetables; (6) other vegetables and fruits; (7) eggs; (8) lean meat, poultry, and fish; (9) flours and cereals; (10) butter; (11) other fats; (12) sugars.

This has several advantages. It gives people a wide choice among individual foods, so that if they do not like a particular food, or if they cannot afford it, or if it is temporarily scarce and high-priced, they can take some other food from the same group and still be sure that the diet as a whole is properly balanced. In other words, arranging a diet by quantities of food groups permits the maximum flexibility without being so loose and vague that there is danger of missing something important, or so specific that only a few people would follow the recommendations.

But even this would not be enough to suit all income levels. Not only do individual foods differ in price; some groups of foods always tend to be higher priced than others because of the economics of production. People who have very little to spend for food are practically compelled to cut down on the milk-and-milk-products group, the egg-meat-fish group, and the citrus-tomato group, for example, and to place more emphasis on flour and cereals, potatoes and sweetpotatoes, and dry legumes and nuts. And the more this kind of substitution is necessary, the harder it is to arrange a diet that will give real protection against those ills that come from getting too little of some very important mineral or vitamin. For, broadly speaking, the foods that tend to be more expensive are often the ones that are richest in these vital protective elements.

This is the reason why there are four diet recommendations rather than only one.

One plan is called "an expensive good diet"; it includes liberal quantities of the more expensive— and in general more highly protective—food groups. Even here, it is possible to be comparatively economical, or to go in for the highest-priced foods or those especially valued for certain qualities of flavor.

Another plan is called "a moderate-cost good diet." Nutritionally, this is about equal to the more expensive good diet, but it is worked out with economy definitely in mind.

Another plan is called "a low-cost good diet." Here the quantities of certain protective foods are less liberal, but the diet is still definitely good.

Each of these three plans allows a margin of safety that, according to modern knowledge, will contribute to better-than-average health.

Finally, there is "an economical fair diet." The use of the word "fair" instead of "good" is the significant point here. In this diet the quantities of protein and of important minerals and vitamins are considerably closer to the minimum necessary for protection than they are in the good diets. The fair diet is considered adequate for protection, but it is highly probably that any diet below this level, followed for any length of time, would be dangerous to health in one way or another. Yet many people are below this level habitually.

The four recommended diets are given in four tables in the article on Planning for Good Nutrition and cannot be repeated in this brief summary. The tables show the quantities of each of the 12 food groups for individuals of different ages and degrees of activity, so that they can be used in making plans for an entire family. They can also be used as a basis for bringing food production at home definitely in line with good nutritional standards.

These dietary recommendations are not to be considered as ideal. Some nutritionists would undoubtedly go beyond them in certain respects. But the recommendations are based not only on what is desirable, but on a painstaking study of existing American food habits, which affect both our production and our markets. The suggested plans take these habits into consideration instead of recommending what might be ideal but not in line with our habits.

Two things should be kept in mind as a result of the great mass of modern nutritional research. The first is that free choice of foods is not a safe guide to good nutrition at any economic level unless it is backed by understanding, any more than instinct is a safe guide to avoiding disease. Knowledge is necessary, and the well to do as well as the poor can lack this knowledge and suffer from nutritional deficiencies as a result. The second is that good nutrition cannot be attained without going to some trouble and taking thought. Even the simplest rule-of-thumb method requires some trouble in meal planning. Until we are all so accustomed to right eating that it becomes practically automatic—if that is possible—we shall have to use just as much care here as we do in other things that are vital to health.

MICRO-ORGANISMS IN FOODS AND FOOD PRESERVATION

Micro-organisms spoil foods, and they are also used to make and preserve foods. In one sense even the spoilage organisms are beneficial. They take part in the process of decay by which the earth gets rid of surplus material and uses it over again for new living things.

Fruits are attacked principally by yeasts and molds, which can tolerate the fruit acids. Cold storage, which slows up the living processes in the picked fruit and retards micro-organisms, is the principal method of preservation, though wrapping and surface coating are also used. Fruit juices are attacked by molds, and they are also fermented by yeasts, which convert their sugar into alcohol and carbon dioxide; then bacteria convert the alcohol into acetic acid. Pasteurizing, filtering, and freezing are used to prevent these spoilage processes. In the case of vegetables, bacteria and molds are the attacking organisms; some of the bacteria convert soluble sugar into sour-smelling lactic acid. Fresh vegetables should be handled rapidly, kept cool with a free circulation of air, and not placed in large containers or piles.

In the case of frozen foods, the secret of preventing spoilage lies almost entirely in using absolutely fresh products and handling them properly before freezing and after thawing. In the case of canned foods, improper processing permits certain micro-organisms to survive, including bacteria that produce gas, which swells the can, and others that produce acid, which turns the food sour. Eggs that are improperly handled may become heavily infected with bacteria, which cause decomposition. Eggs to be broken and frozen must be handled with special care. Milk is readily soured by lactic acid bacteria or otherwise spoiled by micro-organisms. The preventives of spoilage are sanitary handling, cold, and pasteurization. Meats can be kept comparatively free of spoilage by proper cold-storage methods, and by salting, smoking, drying, and freezing.

The use of micro-organisms in the manufacture and preservation of foods includes wine and beer making by controlled fermentation with yeast; vinegar making with bacteria that convert alcohol into lactic acid; bread making with yeast, which produces carbon dioxide that causes the dough to rise; the making of pickles and sauerkraut with bacteria that convert sugar into lactic acid; cheese making with bacteria and, in some cases, molds; butter making with lactic acid bacteria that turn the cream sour; and the production of various sour and fermented milk drinks. In many of these processes, the particular micro-organism used produces a distinctive flavor that is valued in the finished product.

ENZYMES IN FOODS AND FOOD PRESERVATION

In general, the same precautions used to prevent spoilage by micro-organisms are also used to prevent spoilage by enzymes. Whereas micro-organisms must enter food materials from the outside, enzymes are chemicals that are already present in the food; in fact, they are a part of it, necessary to life processes. After the death of the food material many of these enzymes continue to function, causing the food substances to disintegrate—a process known as autolysis or self-digestion.

Fruit is still alive when stored, and it continues to take in oxygen and give off carbon dioxide at an increasing rate until it is fully ripe and to undergo internal chemical changes. The "breathing" or oxidation depends on enzymes. In the process, heat is produced. A great deal of heat may be produced in a cargo of fruit, and it builds up rapidly. For this reason, precooling is extremely important to slow down respiration before shipping or storage and minimize the build-up of heat. A high concentration of certain gases—carbon dioxide or ethylene—will also slow down respiration.

Meat is dead when stored and does not respire, but enzymes cause other changes, among them the decomposition of protein and of fat.

Both low temperature and carbon dioxide are used to slow down the decomposition processes. In a recently developed method, the meat is encased in a tight-fitting rubber bag.

Eggs deteriorate very rapidly and should be brought to a low temperature as soon as possible after being laid. A few hours at this time may mean a difference of several weeks of possible commercial storage. It is also important to prevent evaporation in eggs, since this increases the size of the air cell and lowers the candling grade. Low temperatures (above freezing) are used for egg storage, as well as carbon dioxide. The shells may also be coated with oil to seal the pores. Sometimes air is pumped out of the egg with a vacuum pump before the oil is applied.

The whole problem of food storage is extremely important for man because of its effect on economy of production and on assuring a continuous and convenient food supply. Scientific research has made possible many things that could not be done in the past, but there is little doubt that the future will see achievements in safe storage that may be even more revolutionary.

UNITED STATES MEAT INSPECTION

Meat inspection by the Federal Government began in 1890. Today about two-thirds of the domestic meat supply—mostly the part intended for interstate shipment—is prepared under Federal supervision and inspection. Imported meat foods are examined for compliance with United States requirements. The stamp or label, "U. S. Inspected and Passed," is the consumer's assurance that the meat or meat product was derived from healthy animals and was prepared in a sanitary manner.

Inspection begins at the packing plant with the live animal. Unfit animals are promptly condemned and destroyed, and any in doubtful health are marked and placed aside for special slaughter and inspection. Throughout the whole process of slaughter and preparation, the carcass and its parts are repeatedly examined, and eliminations may be made at any point. Repeated inspections are also made throughout the preparation of meat products. Nonmeat ingredients used in these products must also be officially approved. Pork products intended to be eaten uncooked must be subjected to special treatment at inspected establishments to destroy trichinae that may be present in the meat. False and deceptive labeling is prohibited. Packing plants must be constructed and equipped in prescribed ways to insure sanitation and provide facilities for inspection. Several hundred veterinarians and assistants are engaged in this extensive work.

A large amount of unfit meat is destroyed each year, though it amounts to only a small proportion of the total prepared for consumption. In many cases danger spots in different parts of the country for the spread of animal diseases have been located as a result of the meat-inspection work.

SUPERVISION AND INSPECTION OF MILK

Most of the control over market milk and cream is exercised by State and municipal authorities. There are three objectives in this work:

(1) Maintenance of nutritive value. State laws still show a considerable variation in the minimum content of fat, solids not fat, and total solids in fluid milk, though the trend is toward uniformity.

(2) Prevention of fraud. Fraudulent labeling—"Special Baby Milk," for example—has been greatly reduced, though some doubtful claims are still made.

(3) Sanitation. Most milk inspection centers around sanitation. Almost all cities and towns have milk-inspection ordinances, but some communities are quite apathetic about enforcing them, though the cost per capita is very small—not over 10 cents a person a year. Sanitary inspection begins with examining the cow for certain diseases and infections such as bovine tuberculosis, Bang's disease, and udder infections. Personnel, quarters, and equipment at the dairy must be inspected. Bacterial counts on milk are made with varying frequency in different communities. Milk-pasteurizing and processing plants must have close supervision.

Many cities classify milk into grades. These vary considerably, but several hundred localities have adopted a uniform system advocated by the United States Public Health Service.

FOOD GRADES AND THE CONSUMER

Grade standards are in use for most food products, but they were mostly developed for the wholesale trade and the use does not reach through to the consumer. A dealer need not look at a properly graded product; he can buy it by grade and know what he is getting, since the grade stands for certain well-defined qualities. In most cases, the Federal Government or the States set these commercial grades, which may be either prescribed or voluntary.

The consumer can seldom buy by objective grades like the dealer. He can only hope that he will get a better grade if he pays a better price. Yet commercial grades are for the most part based ultimately on consumer preferences, and if it is possible to grade a product for the dealer, it should in many cases be possible to grade label it for the consumer. The consumer would thereby get the same kind of advantage the dealer gets. He could be more sure of getting his money's worth, and to the extent that he could buy more efficiently, his real purchasing power would be increased.

Where consumer grade labels were used, they would have to be as simple as A, B, C or 1, 2, 3. It is possible for grade labels to be so confusing as to be useless. Consumer grade labels should be uniform as between different foods. Grade labels would not necessarily eliminate private brand labels. Some canners and others are already labeling canned foods with A, B, C statements of quality.

Meat, butter, and eggs are now sold in some places by consumer grade labels. Sanitary inspection and stamping for wholesomeness should not be confused with consumer grade labeling. Nor is the term "substandard," which must be used on some food products under the Food, Drug, and Cosmetic Act of 1938, a true grade-label system. It merely indicates that a certain product falls below a certain minimum standard of quality, though it is wholesome and nutritious.

WHAT THE MODERN HOMEMAKER NEEDS TO KNOW

A family Christmas dinner in the Maryland tidewater in 1680: Oysters on the half shell, turtle soup, ham, venison, turkey, duck, potatoes, sweetpotatoes, other vegetables, jellies, conserves, pickles, cider, home-made wine, pumpkin pie, mince pie, apple pie, custards, syllabubs, other desserts, coffee, sweetmeats. Practically none of this was bought at a store, and practically everything was locally produced, home-prepared, and home-cooked.

A modern Christmas dinner in a city apartment with a kitchenette: Cocktail from the drug store in the basement, canned oysters, canned soup, wafers from a box, frozen turkey, canned cranberry sauce, quick-frozen lima beans and spinach, sweetpotatoes, salad with dressing from a jar, pie from canned pumpkin and canned mincemeat, raisins and salted nuts from packages, coffee. Every item comes from the store, almost all are assembled from distant places, and home preparation is reduced to a minimum.

The contrast shows what has happened in a money economy where production and processing have become commercialized and very few people any longer produce anything for themselves.

The change demands new skills on the part of the housewife. She no longer has first-hand knowledge of a hundred things her ancestors knew about food production and preparation. Her early training is entirely different. At the same time, modern methods have added enormously to the cost of food for the consumer. In the city especially, her need now is to know, not how to produce, but how to get the most value for what she spends; and this involves first a knowledge of the what and why of a good diet, in terms of food groups in which individual items can be shifted around to meet the demands of economy. She needs to be able to make a broad diet pattern, to plan meals well ahead, to take advantage of bargains and shifts in food prices. She needs to know brands and grades from the standpoint of quality, and the nutritive values of unrefined as compared with refined foods. Basically, in fact, she is a purchasing agent nowadays, and she needs to be a wise and canny purchasing agent.

On the farm, the situation is different. Good nutrition is very largely an economic as well as a physical problem, and much may be gained by adapting the older skills in food production and food preparation to modern needs. Farm people can have good diets at a low cost if they will short-circuit distribution costs by producing and processing their own foods. But for the greatest effectiveness, this too should be done—especially the planning of production—with an understanding of nutrition and food values. The farm housewife can do what her ancestors did and do it more intelligently and more easily with the aid of modern science and some modern equipment. It is a question, too, whether even the city or suburban housewife could not gain economically by doing more processing at home, as in the case of canning and baking.

BETTER NUTRITION AS A NATIONAL GOAL

It is true that we are only at the beginning of knowledge about human nutrition, but it is also true that enough is now known to give better health, greater vigor, and longer, more useful lives to immense numbers of people if the knowledge could be generally applied.

Farmers have much at stake in any effort to do this. They are burdened with surpluses of food that many people badly need. Raising the nutritional level of the Nation would wipe out many of these surpluses completely; and if the level were raised high enough, it would necessitate greater production of some foods than we now have or have ever had.

There is nothing mysterious about the practical application of modern knowledge of nutrition. Leaving out all the technical details, it says simply that the majority of people need to get more milk and milk products, eggs, and certain fruits and vegetables than they now get.

What stands in the way of their getting more? For one thing, lack of money. Many people cannot afford to buy enough of these foods. In a recent survey, it was found that city families in most parts of the country that spent less than $1.25 a person a week for food had poor diets. For another thing, lack of understanding. Even at a quite low level of expenditure it is possible to get a fairly good diet— if you know what to buy. But a great many people with plenty of money do not know, or do not care.

Apparently there is a certain level of expenditure at which people can hardly help getting an adequate diet. That is when they spend at least $6 a person a week for raw food materials. This is $312 a person a year, or $1,248 for a family of four. The income required to permit such an expenditure, assuming that 25 to 30 percent is spent for food, would have to be over $5,000 a year for a family of four. If every family had an income comparable to this and spent this proportion for food, none would need to be ill-nourished.

But there is no possibility that in any near future the problem will be solved in such a generous way as that.

Can progress toward better nutrition be made in any other way?

It can be made (1) if people with more limited food budgets—which means the vast majority—will learn how to get the best diet possible for what they have to spend; and (2) if those at the lowest income levels can have their purchasing power increased enough to attain at least a fair if not a really good diet.

How much increase would this mean for the latter group? Studies indicate that to reach the level of fair nutrition the poorly fed family of average size would have to spend some $60 a family a year more for protective foods than it now spends; and that to spend this extra $60 for protective foods, families now spending $250 to $750 a year for living would have to have an additional $150 to $250 a year. Such figures are tentative, but they indicate the nature of the problem.

Such increased purchasing power, of course, can be attained in more than one way. It can be attained by (1) direct increases in income through higher pay and more and steadier employment; (2) lower prices for food—for example, through lower distribution costs; (3) giving away food, as in the case of people on relief. Or it can be attained by any combination of these methods.

For families living in the country, the problem is somewhat different. They can accomplish much by more and better-planned home production.

Education would have to accompany any of these methods. But education is taken for granted in the United States. The problem here is no different from that in many other aspects of life.

It is hard to escape the conclusion that any widespread, major improvement in nutrition among the lowest economic classes depends in large degree on the first method—directly increasing incomes that are now inadequate. In this respect, nutrition is simply one aspect of the whole problem of improving the standard of living. Yet much could undoubtedly be done by indirect methods.

Those who cannot now afford even an economical fair diet are largely among those with incomes of less than $750 a year. These income classes include 32 percent of all the families and single individuals in the country. An additional $150 to $250 a year would bring their incomes up to an average of somewhere near $750 a year.

How much of an increase in the total national income would have to be made to bring this group up to this level?

If the incomes of everyone else were increased in proportion, the total national income would have to be nearly $100,000,000,000 (1935–36 values). Actually, in 1935–36, it was only $59,000,000,000. Such an increase would certainly have to be a long-time, not an immediate, objective.

But suppose, instead of increasing all incomes, only the incomes of the lowest group were increased up to a level of $750 a year. This would require only about $4,000,000,000 more than the 1935–36 national income.

Or again, suppose the national income were not increased at all. Then, to raise the incomes of the lowest group up to $750 a year, about $4,000,000,000 would have to be siphoned off from the upper levels and added to the lower levels.

These three methods—and there might be others—are given only as examples to show the nature of the problem. In practice, economic policies do not work out in such a clean-cut way. There are always mixtures of various methods.

What stands in the way of achieving a national income of $100,000,000,000, which might put everyone to work and raise all income levels?

One theory is that the present distribution of incomes permits too much saving. Large savings are advantageous in periods of rapid expansion, as in the past in the United States. There is then plenty of opportunity to invest the savings in productive enterprises, and this puts people to work and increases consumption of goods. But when there is no rapid expansion, the savings lie idle. The only way they could be invested profitably on any considerable scale would be in industrial improvements that would lower the prices of consumer goods and thus permit larger volume sales to the vast group of people with comparatively low incomes.

According to this theory, when the distribution of incomes is such that most people are below the average of incomes as a whole, and when other factors of growth are lacking, then it must be possible to keep lowering prices through greater efficiency if there is to be continuous industrial expansion and opportunities for the profitable investment of savings. Lowering prices because of distress will not do. It leads to bankruptcy, not profits.

If this cannot be done, then the savings keep accumulating with no place to go. The amount of idle capital grows larger, the number of idle men also grows larger, prices are forced down below the point where any profit can be made; there is general distress; and through capital depletion, the savings themselves may ultimately be eliminated.

If this viewpoint is correct, then one remedy would be to prevent the accumulation of idle savings. That would mean changing the distribution of incomes just enough so that those at the lower levels would have more purchasing power and those at the upper levels would not be able to pile up idle funds. The theory is that industry would then be stimulated through increased mass purchasing power and there would again be opportunities for profitable investment.

According to this viewpoint, then, to bring about any really large increase in the national income to, say, $100,000,000,000—there would have to be either some great opportunity for expansion, such as the United States has seen in the past, or else an increase in mass purchasing power at the expense of idle savings.

How about the other two possibilities mentioned for increasing the purchasing power of the lowest group only, without waiting for any great increase in the national income?

One way to do this is for the Government to subsidize the lowest group enough to enable them to increase their purchases up to the point where they could be adequately nourished, just as the upper groups have been aided through tariffs, loans, and grants.

There are strong arguments for doing this. It would be a national investment, not in durable goods but in durable consumers—an investment in improved human health and human vigor. It would also take care of some farm surpluses and help to prevent the decline of farm prices to points that mean ruin for both farmers and the soil, as well as for industry.

Free distribution of food to destitute and undernourished families is already an accomplished fact. During the past 4 years, the Federal Surplus Commodities Corporation has bought and distributed to welfare agencies almost 3,000,000,000 pounds of surplus foods.

There are several possibilities for increasing the purchasing power of low-income consumers indirectly by enabling them to buy foods at low prices. One of these is the food-stamp plan now being tried in several cities. According to this plan, families buying orange-colored food stamps are given, free, a certain number of blue stamps, exchangeable for products designated as surplus foods. In effect, the plan increases the purchasing power of these families for all foods by about 50 percent. It is too early to tell how this plan will work. It can readily be modified. It should be given a fair trial and carefully studied as one possible solution for part of the problem of inadequate nutrition in the midst of surplus production.

Again, when the consumer spends $1 for food, less than 50 cents of it goes to the farmer. The cost of the food is more than doubled between the farm and the consumer. This indicates how worth while it would be to reduce distribution costs. The Department of Agriculture is devoting intensive study to this problem.

Now what would be the effect of a higher level of consumption on agriculture?

To raise the level of consumption to that required for everyone to attain a moderate-cost good diet (as outlined in this book) would probably require about 285 to 295 million acres—slightly higher than the acreage required for recent actual levels of food consumption.

To raise the level to that needed for an expensive good diet would require 30 to 40 million acres more than that necessary for recent actual levels of consumption.

To raise the level only to the point where every family could select an adequate diet suited to its income would require no great increase in total acreage, but agriculture would benefit from substantial increases in the consumption of several food products.

There can be no doubt about the ability of agriculture in the United States to meet such changes in consumption if they occurred. There would probably be a quick response to any effective increased demand for any product. The critical question for American farmers is not whether they can meet the demand, but whether, in meeting it, they can be assured of a fair return for what they produce.

PART 2. ANIMAL NUTRITION

SOURCES AND CYCLES OF THE NUTRITIVE ELEMENTS

In general, animals can only release or use energy from foods to meet their own requirements for growth, internal activity, movement, and work. Green plants not only release energy; they can also store up large quantities in excess of their requirements. They capture the energy of the sun and store it away in sugars and starches and many other compounds, which they make out of simple elements obtained from the soil, from water, and from the air. Neither animals nor plants that are not green (such as fungi and bacteria) can use the energy of the sun in this way. They must get their energy supply directly or indirectly from compounds prepared by green plants. All that man has done, including the building of the pyramids and the newest World's Fair, has been done with energy from the sun stored up by green plants.

Plants would exhaust the supply of elements needed to make energy-storing compounds except for one thing—the compounds are broken down as well as built up. Both animal bodies and plant bodies eventually decay. Their proteins, carbohydrates, and other compounds then give up the simple elements of which they are made, and these are returned to the soil, the water, and the air to be used over again by green plants. The process is a great cycle of life in which construction balances destruction. And there are minor cycles for each element used in life processes—a nitrogen cycle, a carbon cycle, a calcium cycle, and so on.

Underneath all agricultural practices there is a guiding principle, but we do not have enough knowledge to see it or follow it clearly. The principle is to carry out this cycle of destruction and construction economically—to see that plants, animals, and man utilize raw materials efficiently to build up the products of life, and that these products are broken down efficiently into raw materials that can be used again. Whoever can devise simple methods that further economical operation of the cycle of life contributes to human welfare.

Gradually we are beginning to see the cycle as a whole—from the soil, through plant life and animal life, and back to the soil again. It is important to see it as a whole if we are to understand the relationships between the various steps in the process and make them operate efficiently.

More and more is being revealed through science about these relationships. For example, the mineral content of the soil affects the mineral content of plants, and this in turn affects the nutrition of animals feeding on the plants. By the proper use of fertilizers and other cultural practices it might be possible to insure the production of plant and animal products of better-than-average nutritive value for human beings. Again, there is evidence that plants take up more minerals—provided the minerals are present to be taken up—when the water content of the soil is relatively high. But certain practices such as excessive pruning or cutting counteract the effect of a good water supply. Again, the amount of green area on the plant, and the amount of light reaching this green area, affect the storage of energy in the form of carbohydrates, and this in turn affects the absorption of minerals. Temperature is also important in the utilization of minerals. By correlating fertilizer practices with temperature and sunlight, it has been possible with some plants—pineapple and sugarcane particularly—to cut the amount of fertilizer used by 60 percent. In the case of many plants it is possible to distinguish four different types of growth produced by different relationships between the carbohydrate supply in the plant and the nitrogen in the soil; and the quality and nutritive value of the plant are markedly affected by the type of growth.

These relationships between temperature, light, water supply, minerals, and probably vitamins and hormones, need much more study. They have a direct bearing on cultural practices, yet little is known about them. The ultimate objective that should be kept clearly in mind is to turn out products of uniformly high nutritive value for human beings. That means studying the human beings as well, in order to determine the effects of products produced under different conditions.

Research is necessarily a piecemeal process; it attacks one phase at a time. But the pieces are interrelated, and it should be possible to link them together in a correlated program.

THE DIGESTIVE PROCESSES IN DOMESTIC ANIMALS

The digestive tract is a tube, enlarged in certain places to form compartments, each with a special function. Different species of animals have different arrangements, partly dictated by the kind of food they mainly eat—plant food, animal food, or both. In all animals, the food is mixed with digestive juices and pushed along the tube by muscular movements.

In grazing, the horse seizes food with its flexible upper lip and front (incisor) teeth. The cow uses a long muscular tongue and tears off herbage with the lower teeth and upper gum, since it has no upper front teeth. The fowl picks up food with a toothless beak. In drinking, the horse, cow, sheep, and pig use the tongue to create suction in the mouth. The dog and cat lap with the tongue. The fowl scoops up liquid and lifts its head to let the liquid run down the throat. The pigeon sucks up liquid by the use of the tongue.

In chewing, the hinged lower jaw of mammals moves against the rigid upper jaw and food is crushed between the upper and lower grinding teeth. Some animals have three kinds of teeth—molars in the back of the mouth for grinding; incisors in the front, for cutting; canines, between front and back, for seizing food and for fighting. Others lack the canine teeth.

Ruminants (cattle and sheep, for example) chew their food partly; then swallow it into a temporary storage stomach (rumen); then regurgitate it and chew it over again at leisure. Thus a ruminant can take quickly a good deal of food on pasture and chew it later at its leisure. Grain is usually ground for cattle because it is not regurgitated for this second chewing. Cattle have a deep transverse groove in the tongue that is easily injured by sharp or spiny substances. Man and the pig have a starch-digesting substance (ptyalin) in the saliva, but with most domestic animals, the saliva is mainly a lubricant for foods. The horse has a narrow throat opening and can swallow very little at a time.

In the capacious first stomach of ruminants, food is subjected to a good deal of bacterial action, which breaks up the tougher walls of plant cells and splits certain carbohydrates. Next the food goes to the second and third stomachs, which are mainly for storing and grinding; and finally to the fourth or true stomach, which is comparatively small and receives food gradually in a well-ground-up condition. Here true digestion takes place.

Other animals must get along without the three preliminary stomachs. The horse has a very small stomach, only large enough to hold a third to a half of what it may eat at a meal; so the food must pass along into the intestine very quickly, without much stomach digestion. The stomachs of the pig, dog, and cat will hold all they can eat at a meal, and food may remain there for some time. In all mammals, food is mixed, softened, and acted on by gastric juices in the stomach before passing to the intestine.

Fowls swallow their food whole. It passes into the crop, a place for bulk storage; then into the small proventriculus or glandular stomach, where it is acted on by pepsin and hydrochloric acid; then into the gizzard, or muscular stomach, where it is crushed and ground by the churning movements of that organ (some grit is retained in the gizzard, thus helping in this process); then to the first part of the small intestine, where it is more thoroughly mixed and digested by juices.

The pigeon is peculiar in that both male and female develop specialized cells, containing a good deal of fat, in the mucous membrane of the crop. The fat and the cells that are shed form a milklike substance, which is regurgitated and fed to the young. This feeding continues for about 20 days after hatching. Pigeon milk has a very high fat and protein content, which may account for the rapid growth of squabs. There is evidence that prolactin (a secretion of the anterior pituitary gland at the base of the brain) incites this secretion.

In the dog and cat, which chew their food very little, digestion by gastric juices in the stomach is prolonged.

The process of digestion is essentially the same in all animals.

Proteins are broken down into simpler products (proteoses and peptone), and then pass into the intestines, where they are still further broken down into amino acids that can be absorbed into the blood. Fats are broken down into fatty acids and glycerol, ready for absorption. Starch and dextrins are converted into maltose, and the maltose is broken down still further into glucose for absorption. Many enzymes, each with specific functions and all neatly interacting, take part in these chemical processes. Most of the final products of digestion are absorbed from the small intestine, but some—particularly in the horse—from the large intestine, which comes after the small intestine. The organs that absorb these products are small fingerlike protuberances (villi) on the mucous membrane of the intestinal wall. The absorbed substances are then carried to all parts of the body, to be utilized for growth, repair, energy, and other purposes.

FACTORS AFFECTING MAINTENANCE NUTRITION, FEED UTILIZATION, AND HEALTH OF FARM ANIMALS

Since cash returns above feed costs are the primary source of income for the livestock farmer, it is important for him to learn as much as possible about the economical feeding of animals.

The first requirement of a mature animal is for enough food to maintain its internal body processes and support normal muscular activity. This amount of food—the maintenance requirement—will keep an idle animal going with its body in nutritional balance. The mature animal that is not idle but producing, whether the production is in the form of work, meat, wool, milk, eggs, or offspring, will require sufficient additional food to meet the demands of this production; and similarly the young growing animal will require sufficient food above the maintenance requirement to meet the demands of growth. If a producing animal, with the exception of the fattening animal, does not receive any more than its maintenance requirement, it will not immediately cease production. It will draw on its own tissues for a time, and permanent injury may result if this is continued too long.

If, then, the maintenance requirement, the growth requirement, and the production requirements of animals were known with a high degree of accuracy for all conditions, the amount of feed needed for any given purpose could be calculated by simple arithmetic. Unfortunately this is not possible at the present time, since all of the requirements of animals and the value of various foods in meeting these requirements are not fully known. More is known, however, about the maintenance needs of animals under certain strictly controlled experimental conditions, and with this information as a background, the additional factors influencing the requirements of animals under practical conditions are being given more attention.

What body processes must be covered by maintenance nutrition?

The animal must produce enough heat from food to maintain the correct body temperature. Naturally the amount of food required for this purpose increases when the temperature of the surrounding air goes below a certain critical point, which is different for each kind of animal. Other processes covered by maintenance nutrition include circulation of the blood, glandular secretion, breathing, digestion and assimilation of food, activity of the nerves, normal muscular activity, and excretion of waste products. These processes demand not only heat-producing (energy) nutrients, which include sugars, starches, and fats, but also proteins for repair of tissues and other purposes, and minerals and vitamins.

The energy required for maintenance of animals can be measured by various methods. It has been known for a long time that a relation exists between the body surface of an animal or its body weight and its basal metabolism (the minimum heat production under specified conditions). Recent calculations from metabolism data on animals varying in size from mice to elephants show that the basal metabolism of an animal can be calculated with some accuracy from its body weight. This, however, would be the minimum requirement; it would not include such factors as unusual muscular activity or low surrounding air temperatures or other conditions that would increase the maintenance energy requirement in a variable manner.

The protein required for maintenance has also been calculated to vary as a function of body weight, and in addition it is affected by other factors such as age and production. The young growing animal requires a great deal of protein for new tissues whereas the mature, nonproducing animal needs little more than enough for upkeep. "The protein requirement," however, is a very loose term, although its meaning is generally understood. What animals require for growth and upkeep is not protein, but certain essential amino acids, which are constituents of proteins. There are thousands of different kinds of protein, and those present in foods vary considerably in their usefulness to the animal body, depending on how much or how little of the required amino acids they contain. This point is amply covered in other articles in this book. From the practical standpoint, it means that as sources of protein some feedstuffs are very useful while others are unreliable or uneconomical or both.

Protein is usually a relatively expensive feeding material, and it is most economically used for maintenance when only enough is fed to meet the needs of body building and upkeep. This means that enough carbohydrates and fats must be fed to meet the energy needs of the animal. Protein will not be used efficiently if this is not done. On the other hand the body can obtain its energy largely from protein if necessary.

Other factors also affect the economical utilization of feeds. For example, when vitamin D is inadequate, phosphorus and calcium assimilation is interfered with, causing large losses of these minerals; and with too little vitamin A, vitamin G, or phosphorus the appetitite is depressed in addition to other harmful results.

Overfeeding, or improper feeding, on the other hand, may be as harmful as underfeeding, and it has caused large losses of livestock through digestive disturbances that are sometimes sudden and quite often severe enough to be fatal. This is especially likely to occur, of course, when animals are on a fattening ration with little exercise, as in the case of lambs or cattle being prepared for market.

An animal has a good deal of ability to make up for moderate undernutrition if it is fed well later on, but marked deficiency of certain minerals and vitamins may be permanently damaging. Breeding and pregnant animals especially need adequate rations.

GROWTH, FATTENING, AND MEAT PRODUCTION

Growth is the basis of meat production. The young growing animal adds weight mostly in the form of protein and water, the mature animal mostly in the form of fat, but there is no sharp line where one kind of gain ends and the other begins. Animals grow at an increasingly rapid rate up to a certain point, then at a decreasing rate until growth ceases. As weight increases, it takes a larger and larger amount of feed to produce a pound of gain—or in other words, the efficiency of feed utilization decreases.

A great many changes occur during growth. One of the most obvious, in meat animals, is that the proportion of dressed carcass to the entire body weight increases as growth proceeds. In a 60-pound pig, for example, the dressed carcass is about 66 percent of the live weight; in a 380-pound pig, it is about 80 percent. In cattle the range is from approximately 42 to 60 percent; in lambs (unshorn), from 33 to 53 percent.

At the same time there are changes in the proportions of different parts of the body. As a hog grows and fattens, for example, the percentages of ham, loin, shoulder, and head cuts decrease. Characteristic changes in the proportions of different cuts also occur with cattle, lambs, and poultry. Any significant increase or decrease in proportion of a major cut is important because of its effect on carcass value.

Changes also occur in the composition of the meat. In general, the proportion of protein and water tends to decrease and the proportion of fat to increase after a certain stage of growth. The proportion of mineral matter—largely represented by calcium and phosphorus in the bones—usually decreases slightly. In a 50-pound hog, for example, water may be 61 percent of the empty body, fat 20 percent, protein 16 percent, minerals 3 percent; at 325 pounds, water may be 34 percent of the empty body, fat 54 percent, protein 10 percent, minerals 2 percent. Exceptions to these trends have been noted in some animals. The distribution of fat in different parts of the body changes also, and there are changes in the fat content of lean tissue. The ratio of edible meat to bone in the dressed carcass increases with heavier weight.

A simple, accurate method of measuring the efficiency with which feed is used for growth by different animals or the same animal at different times would be extremely useful both to the animal breeder seeking efficient strains and the nutritionist comparing the values of different diets. Such a method has been worked out in the form of an equation that can be used in technical work. Short cuts have also been worked out for estimating important factors in the composition of the animal body or the dressed carcass; these methods depend on finding some mathematical relationship between an unknown factor and one that can readily be measured.

SOME EFFECTS OF NUTRITIONAL LEVELS

Growth as a whole is a fairly regular process, but it is the product of changes that actually occur at different rates in different parts of the body. These parts have a definite order of development. For example, the limbs develop early, the middle of the back last. The bones develop earlier than muscle, and muscle earlier than fat. Muscle develops latest over the loin. Essential organs of the body develop much earlier than tissues that store nutrients, such as fat and muscle. Such comparisons can be carried out in considerable detail.

These are inherent characteristics of growth in an animal. But they can be affected by nutrition. For example, the early-developing parts and tissues can be speeded up in their growth by feeding at a high level while the animal is young, and the late-developing parts can be reduced by feeding at a low level later on.

An experiment of this kind was carried on in England with hogs. Young pigs of similar inheritance were fed to a weight of 200 pounds in four different ways: (1) High level throughout; (2) high level early, low level later; (3) low level early, high level later; (4) low level throughout. Their carcasses proved to have quite different characteristics, depending on what parts were speeded up or slowed down by the level of feeding at the time when those parts would naturally have developed. For example, it was possible by this kind of control to produce a pig with relatively more loin and less head; more fat and less bone; more muscle and less fat.

Fundamentally, this is the way bacon-type and lard-type hogs are produced from animals of the same breeding. The same general rule should hold with other livestock. Exercise, however, introduces a variation by preventing the formation of fat.

The reserve supply of nutrients in muscle, fat, and bone plays an important part in tiding the body over periods of undernourishment. These reserves can then be drawn upon to supply more vital organs. They may also be used during reproduction and lactation. It has been suggested that many animals cannot meet their calcium requirements during lactation without drawing on the reserves, even though they are well fed.

The level of nutrition apparently has an effect on length of life—and a high level does not necessarily mean a long life. At least, rats fed a limited amount of energy-producing foods lived longer (though they weighed less) than those fed an unlimited amount. The rats on the limited diet, however, received adequate quantities of vitamins and minerals.

THE RELATION OF DIET TO REPRODUCTION

Fertility in livestock has always been a matter of great importance to farmers, yet even with good nutrition and management 20 to 50 percent of livestock matings are infertile. Studies made in England, for example, show that more animals are discarded from dairy herds for reproductive failures than for any other reason.

There are so many possible causes of failure to reproduce that it is difficult to make a diagnosis in any given case. Yet to apply remedies without knowing the cause may actually make the trouble worse. Suppose, for instance, that an animal whose infertility is inherited is treated with medicines, gland extracts, or dietary remedies, and then saved for breeding. The inherited infertility will be passed on to offspring, and there will be just as much or more need for treatment in the next generation.

There are too few data to indicate whether there is any one major cause of sterility, though one authority believes there is good ground for thinking that infection is the chief cause. At least, this should probably be the first cause to look for in making a diagnosis. From a practical standpoint, one of the simpler causes of lowered fertility is failure to mate animals at exactly the right time, which is at or after the middle of the heat period in the female.

There is no question that diet is closely related to fertility. To say that any specific element in the diet is necessary for normal reproduction, however, is quite another matter. This claim has been made for several different nutrients on the basis of experimental work in which the nutrient in question was left out of the diet, and the animal failed to reproduce normally or actually developed a disease involving the reproductive organs. In almost every case, however, the animal also refused to eat a normal amount of food when some necessary element was left out. It is known that undernutrition decidedly, even dramatically, interferes with reproduction. Was the reproductive failure in these cases due to lack of the missing element, or to starvation? It is impossible to decide on a critical examination of the evidence.

In other words, there is good reason to believe that whatever is necessary for the normal development and health of an animal is also necessary for normal reproduction as distinct from the other functions of the body. The animal must have the right diet if it is to be normal, reproductively and otherwise.

It should be noted, moreover, that much of the experimental work on nutrition and reproduction has been done with small laboratory animals, especially the rat. Such experiments indicate what to look for in the case of other animals, but the results cannot be taken as directly applicable to other animals.

In the case of two vitamins, A and E, there is evidence that deficiencies do interfere with reproduction.

A minor deficiency of vitamin A quickly affects the soft membranes in the reproductive organs of the female rat. The heat cycle, the formation of ova, and the early development of the fetus are not affected. But difficulties appear about the middle of pregnancy, resulting in hemorrhage or abortion; or birth is delayed, labor is unusually long, many of the young are stillborn, and many of the mothers die in labor. Severe deficiencies affect the testes of the male. Both the male and the female can be cured by doses of vitamin A. Abnormal young invariably occur with the cow and the sheep on diets low in vitamin A. Apparently the deficiency of vitamin A in such cases may be so small as to have no apparent effect on general health.

Vitamin E deficiency also leads to reproductive troubles in the female rat, but again only after the middle of pregnancy, when the fetus is reabsorbed in the uterus. In the male, the cells that produce sperm are affected, and this condition cannot be cured. It has so far proved impossible to reproduce these effects experimentally with other animals, in spite of claims made for the curative power of vitamin E in cases of sterility.

Phosphorus deficiency in range plants interferes with normal reproduction in cattle, but the evidence is never clear-cut because protein is also deficient—and perhaps other factors too—and the cattle do not eat normal amounts of food. There is a widespread impression that manganese deficiency interferes with the heat cycle and the formation of ova in the female rat, but the trouble was actually found to be due to a low-energy diet. Sterility has been produced in the male rat by a diet deficient in manganese, but these results have never been adequately checked.

There are indications that some factor, not yet identified, in roughage plants, may be necessary for normal reproduction in cattle. This needs further investigation.

THE RELATION OF NUTRITION TO THE PRODUCTION OF HIDES AND WOOL

Nutrition is one of the factors influencing the growth of hide and hair, including wool, but little research has been done in this field. In a study comparing the hides produced by full-fed and underfed lambs, those of the first group averaged 0.02 inch, or nearly 77 percent, thicker, were stronger, and had greater tear resistance and better grain than those of the underfed lambs. The strength of cross sections of equal area was approximately the same. Very fat animals may produce skins with a higher percentage of fat, which sometimes causes fatty spots or "kidney grease," a common defect in heavy cattle hides. For the production of leather of the best quality, therefore, it would seem that the ration should be neither too limited nor too full.

Wool fiber is composed chiefly of keratin, a protein that also forms hoofs, nails, and hair. Keratin has a high content of cystine, a sulfur-containing amino acid. Much of the research on the relation of nutrition to wool production has been on the requirements for proteins containing cystine, but there have been no very conclusive results. Feeding trials indicate that the protein requirements of sheep are not particularly high and that protein in excess of that needed for maintenance and growth has little effect on wool production. A high carbohydrate level, however, was found to increase the weight of the wool by 100 percent, probably because the extra energy from the carbohydrate released protein for wool production.

Research indicates that rations which maintain sheep in good condition tend to produce heavy, good-quality fleeces. Sheep on a low plane of nutrition produce lighter, finer, crimpier wool with fibers that break easily, and malnutrition may result in shedding of fleeces. Improper feeding for even a short time will cause a reduction in the diameter of wool fibers, and disease and parasitic infestations have the same effect.

THE NUTRITION OF VERY YOUNG ANIMALS

Before birth, mammals are nourished through tissues (the placenta) connecting the unborn young with the mother's body. There is not a direct exchange of blood, however; nutrients must pass through a membrane separating mother and fetus. In some species (human beings and rodents) this membrane is very thin—only one layer of cells. In others (dog and cat), it consists of two or three cell layers. In still others (pig, horse, and ruminants) it consists of many cell layers.

In animals with a thin membrane, antibodies that confer immunity to certain diseases pass through from the mother's blood to the fetus. In those with a thick membrane, the mother apparently cannot transfer immunity to the fetus. In the latter case, then, it is especially important for the young to get antibodies immediately after birth.

Normally, newborn mammals get these substances, which give them their first or passive protection against some diseases, in the colostrum or first milk of the mother. The antibodies are closely associated with certain proteins (globulins) in the blood serum of the mother and apparently pass into the colostrum with these proteins. When no colostrum is available for feeding the newborn—as when the mother dies—blood serum of the same species may be substituted, either fed to the young animal or injected or both. This has been successfully done with calves, foals, and lambs. As they get older, animals develop their own active immunity against diseases.

The colostrum is a food especially suited to the needs of the newborn. It has a higher concentration of solids, especially proteins, than the later milk. Within a few hours after the birth of young, the milk of the mother begins to lose the characteristics of colostrum.

The milk of different species of animals differs considerably, and presumably each kind of milk is especially suited to the needs of a particular species. In general the more rapid the rate of growth of the young, the higher the concentration of protein and minerals in the milk. There are also differences in the percentages of fat and milk sugar, and in the composition of the proteins. The unfavorable effects sometimes resulting from the feeding of milk of one species to the young of another species are probably due in part to certain characteristics of the proteins.

In the practical feeding of young animals, it is important that they receive colostrum or blood serum shortly after birth. Subsequently, they will do best if they can receive the milk of the dam throughout a normal suckling period. Orphan animals, however, must be artificially fed. Dairy calves and the kids of milk goats are artificially fed at a very early age because of the value of the dams' milk. It is very important to use correct formulas when artificial feeding is practiced.

The calf should be left with the dam from 1 to 4 days. Then it is generally fed whole milk for 2 weeks. This is gradually replaced with milk substitutes—fresh skim milk, dried skim milk with water added, gruel, or dry meal. The calf begins to nibble at dry feeds when 2 to 3 weeks old.

Foals should be allowed to suckle for 6 months or longer, although under some conditions it is practical to reduce this to 3 or 4 months. Orphan foals may be fed modified fresh cows' milk or a mixture of dried whole milk, dried skim milk, sugar, and water, which approximates mares' milk in the proportion of the nutrients. The foal will usually begin eating some grain at about 3 weeks of age, and increasing amounts may be fed thereafter, plus good legume hay as soon as the foal will eat it.

Kids are generally removed from the dam after the colostrum feeding period and fed from bottles or pails. Either goats' or cows' milk may be used. At 4 weeks, alfalfa hay and a grain mixture are made available and gradually substituted for milk. Three months is probably a long enough milk-feeding period.

Lambs are usually allowed to run with their dams for 3 to 5 months. They begin to nibble feed at 10 to 16 days of age. Green alfalfa hay and a grain mixture may be fed if pasture is not available. Orphan lambs may be raised on whole cows' or goats' milk, or a 20-percent mixture of dried whole cows' milk and water.

Pigs are usually weaned at 8 to 12 weeks of age. Supplementary feeds—corn or a mixture of ground grain, a protein supplement, and a mineral mixture—should be supplied to them from the time they are 3 weeks old. Anemia is common among young pigs without access to sod or soil; it may be prevented by giving iron and copper. Experiments indicate that orphan pigs after about 2 weeks of age may be fed with good results on cows' milk with a protein supplement, grain, a mineral mixture, and pasture.

Puppies are usually allowed to suckle for 6 weeks. It is well to begin giving some solid food (chopped or ground lean meat and dry bread, dry cereal, or puppy biscuit moistened with milk or broth) at 3 to 4 weeks of age. Fresh cows' milk is not satisfactory for feeding very young puppies. Canned condensed milk may be used, or whole dried milk with water, or combinations of whole milk with egg yolk or with cream and casein.

NUTRITIONAL REQUIREMENTS OF BEEF AND DUAL-PURPOSE CATTLE

The energy requirements of beef cattle for maintaining body functions and normal muscular activity, exclusive of the requirements for growth, fattening, gestation, and lactation, have been computed by a number of workers and set down as standards for animals of different weights. Some of these proposed standards give a more liberal allowance than others.

Additional energy over and above maintenance is required for growth and fattening. In fact the energy requirement for fattening is limited only by the amount of energy-producing foods the animal can eat. The greatest efficiency of feed utilization has been found in feeding at a rate slightly below the maximum capacity to eat, but full-fed steers usually make the greatest return to the producer. Perhaps the best method of measuring the eating capacity of steers is by self-feeding. There is evidence that when this is done, the steers eat more feed in the earlier and less in the later period of fattening, which is the opposite of the common practice in hand feeding and suggests that hand-feeding methods may need to be changed. Energy standards for growing and fattening have been proposed, but there is room for a good deal more experimental work on various aspects of the problem.

Protein requirements for maintenance, which are important in wintering beef cattle, have also been worked out in a number of proposed standards, as well as the protein requirements for growth and fattening; but even more than in the case of energy requirements, there is need for further careful experiment to ascertain the most effective level of protein feeding. For lactation, 0.04 to 0.05 pound of additional protein per day for each pound of milk produced has been recommended as adequate for beef cattle. In gestation, the protein requirement is low up to the last 3 months, and highest—nearly half a pound a day—in the last month.

Like other animals, cattle require a considerable list of minerals; others may be present in the body not because they are required but merely because they are taken in the food. The two most likely to be lacking in the diet are calcium and phosphorus, which with the aid of vitamin D form the bones and teeth.

In phosphorus deficiency the content of inorganic phosphorus in the blood decreases, and this has been found useful not only as a measure of the state of phosphorus nutrition but as a means of locating phosphorus-deficient range areas. The closest study of phosphorus deficiency has been made in South Africa, where the problem has been acute. Phosphorus deficiencies occur in many parts of this country and have been especially studied in Minnesota.

The approximate calcium and phosphorus requirements for growth (to 400 pounds) are 0.4 and 0.3 percent, respectively, of the total dry ration; for fattening (at 900 pounds), 0.2 percent for each mineral; for late pregnancy, 0.4 and 0.3 percent; and for lactation, 0.3 and 0.25 percent. These can be supplied by using the proper feeds when the mineral content of the feeds is known. In areas where the soil and forage plants are deficient in minerals, a mineral supplement may be used. Excellent results have been reported with bonemeal in phosphorus-deficient areas in South Africa, and there are favorable reports in the United States. Dicalcium phosphate or disodium phosphate may also be used, but these are unpalatable to animals and must be hand-dosed or fed in palatable mixtures. Disodium phosphate is soluble and can be supplied in the drinking water. The United States Department of Agriculture and the Texas Agricultural Experiment Station are now experimenting in feeding various mineral supplements to cattle, with favorable results so far, as compared with the animals not receiving the supplements.

Iodine deficiencies are quite common in the Northwest and upper Mississippi Valley, producing goiter and weakness in newborn calves. In Florida, favorable results have been obtained in feeding cobalt as a supplement to a basal ration of Natal grass hay, shelled corn, and powdered skim milk.

A deficiency of vitamin A or carotene affects normal calving and a more severe deficiency results in night blindness and other serious symptoms. It has been shown that cattle develop symptoms of vitamin A deficiency—including irregular breeding, abortion, and weak calves—when fed on ranges depleted of carotene by an extended dry period. The condition may be corrected when it is not too severe. Two methods have been devised for detecting stages of vitamin A deficiency in range cattle earlier than detectable night blindness—one by measuring the level of blood carotene, and the other by examining the head of the optic nerve with an optical instrument. Various experiments have been conducted to measure the carotene requirement of both mature beef cattle and calves. The requirement increases during gestation and still more during lactation.

Special attention to the vitamin B complex is apparently not required in the case of cattle, though there is insufficient evidence as to whether any of the various individual factors in this complex are required in the feed. Vitamin C also is made in the bodies of cattle. Vitamin D, or its equivalent in sunlight, is required for the prevention of rickets in calves.

PRACTICES IN THE FEEDING OF BEEF AND DUAL-PURPOSE CATTLE

In the range country of the West, beef cattle production depends almost entirely on grass. In the Middle West it depends largely on grain. There are various combinations of these two types of production, but the availability of grass is always the determining factor.

In the grass country, winter feeding and summer feeding present different problems; and in winter feeding, somewhat different practices are followed for the various classes of beef cattle.

Generally the breeding herd is wintered in the feed lot, though there is a growing tendency to reserve range or pasture for winter grazing. In the Southwest and South, many cattle have to depend on range the year round. Winter losses and malnutrition take a heavy toll. This situation can be improved by feeding concentrate supplements such as cottonseed meal. In the northern Great Plains area, experiments indicate that the use of concentrates should be limited to seasons when the winter range conditions are severe. In areas where winter range cannot be provided, hay or silage, sometimes supplemented with protein concentrates, is used. New processes for curing silage might be of value in the South, where forage and hay crops cannot well be cured by drying. Breeding cows should be wintered so as to be in thrifty condition in the spring.

Calves are preferably dropped in the spring. The following winter (after weaning) they should be liberally fed. There are few places where range alone is sufficient for the proper development of the calf. Experiments in Montana show that calves and yearlings can be wintered satisfactorily on alfalfa hay alone, and in New Mexico, on range plus cottonseed cake—one-half pound per head daily for calves, 1 pound for yearlings.

The common practice is to winter bulls in sheds or feed lots and feed them liberally on grain, protein concentrates, and hay or silage. They can be wintered on range if it is possible to give daily supplemental feedings.

Steers to be developed into 2-year-old feeders on summer range should be fed during the first winter to gain 25 to 50 pounds per head, and to keep in thrifty condition during the second winter. Experiments in South Dakota show that under the conditions prevailing there, supplemental feeding may be limited to periods of extremely cold weather or snow-covered vegetation.

In summer, most beef cattle are turned on range or pasture. The important problems are rates of stocking and methods of handling pastures (for example, the use of fertilizers and methods of grazing such as continuous and alternating). When pastures are heavily grazed, it may be necessary to use supplemental feeds in late summer. Cattle are fattened for market either on grass or in the feed lot.

The increasing demand for lighter cuts of meat has resulted in the production of fat calves and yearlings. Under certain conditions it has been found possible to full-feed well-bred beef calves on grain or concentrate mixtures before weaning and have them fat enough for slaughter at weaning time or a few months later. Three years of feeding tests by the United States Department of Agriculture in Missouri showed that suckling calves fed shelled corn for 140 days consumed less grain per hundred pounds of gain than those fed corn plus cottonseed cake or oats; but those fed 1 part of cottonseed cake to 8 parts of corn made greater gains, were fatter, and brought a higher price per hundred pounds, so that they more than paid for the increased cost of feed. In fattening calves, a relatively small amount of grain is required per hundred pounds of gain as compared with mature cattle, but the practice is more suitable for farming areas than for range areas. Experiments indicate that it does not pay to feed grain before weaning if the calves are to be full-fed on grain for 5 months or more after weaning.

Fattening steers on grass alone to a full finish can be practiced in comparatively few areas in the United States, but when grain or concentrates are used to supplement grass, only half as much is needed as in dry-lot fattening. Experiments in the bluegrass section of West Virginia indicate that it is not necessary to feed grain during the first half of the grazing season, and that a limited grain ration plus pasture during the last half is better than using a more liberal ration of grain and hay for a short period following the grazing season. Experiments in South Dakota showed that the use of grain supplements plus summer range during the last half of the grazing season made it possible to market slaughter rather than feeder cattle.

Rations for fattening steers in the dry lot vary considerably in different areas. It is important to remember that the various feeds used make different contributions to the whole ration—hence a direct comparison of feeds is difficult. In the Corn Belt, one of the important problems is to secure protein from the cheapest source. In the absence of corn, or in addition to corn, barley, rye, oats, wheat, grain sorghums, beet pulp, molasses, and cottonseed meal and hulls are used in fattening rations in various areas. Experiments indicate that it is best not to feed more than 3.5 pounds of molasses per head daily, and that cottonseed meal and hulls should not be full-fed for more than 90 to 100 days.

THE FEEDING OF DAIRY COWS FOR INTENSIVE MILK PRODUCTION IN PRACTICE

Cows are fitted to live and produce enough milk for their offspring entirely on pasture and roughage, as they did for countless generations before they were domesticated. But no cow can eat enough roughage to produce milk for six or more calves a year, which in effect is the task set for the good dairy animal. It becomes necessary, then, to feed her all the roughage she will eat, and in addition much more concentrated sources of energy such as grains. Experiments prove that she can be kept in good health and near maximum milk yield throughout one entire generation on high-quality roughage and concentrates alone. But her calves, if such a ration is continued into the second generation, will not be fertile. In order to maintain fertility generation after generation, it has been found necessary to provide pasture, if only for 2 months every year.

There are three elements, then, in maintaining the high-producing dairy cow: (1) High-quality roughage, largely to supply an abundance of protective nutrients necessary for health; (2) grain and other concentrates, largely as compact sources of energy; (3) pasture, largely to maintain fertility and make up for possible shortages in the roughage.

The best roughage is legume hay, and probably the best legume is alfalfa. Cows will eat more roughage, however, if it is made up of a combination of legume hay and grass hay—timothy, for example. Half and half is a good proportion. Corn silage might be substituted for the grass hay, in which case the proportions should be figured on the basis of the dry matter in the silage. It is important to use high-quality hay—preferably U. S. No. 1—because it has a much greater vitamin content than hay of poor quality.

A good concentrate mixture consists of 4 parts of corn meal, 3 parts of wheat bran, and 3 parts of one or more of the oil meals, plus 1 percent of salt. The oil meal should be prepared by the old process, without having the oil extracted by solvents.

Good dairy cows, when mature, should be fed as much hay as they will eat and enough of a grain mixture, such as that described above, in addition, to keep them at uniform body weight. This is approximately accomplished by feeding them according to the Savage standard, which is the most liberal of the feeding standards.

Good dairy cows in heavy production, especially in the early part of the lactation period, will often not eat enough to keep themselves at uniform body weight. Under these circumstances they should be fed as much hay as they will eat and as much grain in addition as they will clean up in half an hour twice a day. It is better to let cows lose weight for a few weeks than to cut down their hay consumption and upset their digestion by feeding more grain than they are really hungry for. As the lactation period proceeds and the milk production becomes less, they reach a stage where they will eat enough to gain weight. They should be allowed to gain whatever they have lost and then be kept at uniform body weight.

Cows fed as described here will receive more protein, fat, vitamin A, calcium, and phosphorus than the minimum requirements worked out in experiments so far. Experience has proved that such feeding gives good results over long periods.

Vitamin A is the only vitamin likely to be lacking in dairy cattle rations under practical conditions. A deficiency results first in premature calving and the throwing of weak or dead calves. Experiments indicate that for successful reproduction cows need at least 10 parts of carotene per million of dry matter in the ration. This will be approximately supplied if the ration contains equal parts of grain and hay, and if the hay is U. S. No. 1 clover or timothy. Cows can store up vitamin A on good pasture in the summer to make up for partial deficiencies later on. Concentrated sources of the vitamin are young growing grass or legumes, yellow garden carrots, high-quality alfalfa-leaf meal, and cod-liver oil. Cod-liver oil in large quantities is poisonous to cows, and it also tends to reduce the fat content of the milk. It should therefore not be used for mature animals except in emergencies, and then at the rate of not more than 2 ounces daily for a mature cow.

There is no evidence at present that mature cows under practical conditions ever fail to get sufficient vitamin D from their rations and from sunlight.

Cows in heavy production need an amount of calcium equal to about 0.25 percent of the dry matter of the ration, but this mineral is seldom likely to be deficient under practical conditions of feeding. Phosphorus, however, is deficient in the soil of certain areas in some 11 States, and feeds produced on these soils are low in phosphorus. Recent work indicates that the ration should contain an amount equal to not less than 0.25–0.30 percent of the dry matter. The feeding of concentrates greatly decreases the danger of phosphorus deficiency. In emergencies, bonemeal or some mineral source of phosphate may be added to the food.

It may be assumed that there is no deficiency of iodine unless goiter appears.

Good dairy rations should supply all the nutrients needed by cows. Dosing with vitamin and mineral preparations to make up for poor rations is a highly experimental and sometimes dangerous procedure.

FIGURING THE RATIONS OF DAIRY COWS

Since different roughages contain different quantities of protein, the grain mixture should be adjusted according to the roughage used. If legume hay is the sole roughage, a grain mixture with only 12 percent of protein may be fed. Legume hay and silage, or mixed hay alone, calls for a 16-percent protein mixture; mixed hay and silage, for a 20-percent mixture; grass hay and silage, or silage alone, for a 24-percent mixture. These protein mixtures may be readily made by using definite proportions of such feeds as corn, oats, wheat bran, cottonseed meal, barley, wheat, kafir, hominy feed, gluten feed, dried brewers' grain, linseed meal, peanut meal, ground soybeans, soybean meal, fish meal.

As a source of energy, good hay is worth about 60 percent as much as the usual grain mixture, and silage about one-third as much as good hay. The quantity of roughage fed should not be reduced below the maintenance requirement of the animal— about 1½ pounds of hay to 100 pounds of body weight. (In substituting silage for some of the hay, figure that 3 pounds of silage equals 1 pound of hay.) After maintenance requirements are met, the amounts of grain needed for each pound of average milk produced by the different breeds are: Holstein-Fresian, 0.41 pound; Ayrshire and Brown Swiss, 0.46; Guernsey, 0.52; Jersey, 0.56.

Good pasture is the best feed, but cows will not graze more than 150 pounds a day, and over most of the country the amount grazed will not provide enough nutrients for more than 1 to 1¼ pounds of butterfat a day. Moreover, pastures are usually at their best for only a month or so. Thus it is well at all times to provide as much hay as the cows will eat in addition to pasture. And wherever it pays to feed grain in winter, it usually pays in summer also. The amount of grain needed in addition to pasture can readily be figured for each breed according to production.

In the West, where the alfalfa hay is exceptionally good, it may be economical to feed this alone during the winter, in spite of the lower production that will result. In the Middle Western States, grain may be fed for all production over two-thirds of a pound of butterfat a day; in the East, for all production over one-half pound a day. The total quantity of grain needed can be figured according to production and breed.

PRACTICAL FEEDING AND NUTRITIONAL REQUIREMENTS OF YOUNG DAIRY STOCK

Some 25,000,000 dairy cows 2 years of age and older are kept for milking in the United States and replaced about every 5 years. About 10,000,000 heifers under 2 years of age are being raised to replace them. In addition, probably 250,000 to 300,000 young dairy bulls are raised each year for replacement purposes. These young animals will be the dairy herds of the future, and feeding them properly is important.

The quantities of feed given to heifers should not be figured on the basis of weight alone, but on the basis of both weight and age, to allow for normal gains.

The calf should be fed for the first 3 or 4 days on the dam's colostrum. It should then have whole milk for at least 2 weeks if it is strong and vigorous, or 3 to 4 weeks if it is weak or especially valuable. Calves may be fed without whole milk after the third day if they are given fresh skim milk or reconstructed dried skim milk (1 part of powdered skim milk in 9 parts of water) plus 2 teaspoonfuls of cod-liver oil daily, or 15 milligrams of carotene in oil, or about 7 ounces of grated yellow garden carrots. These supplements which are used as a source of vitamin A—may be safely omitted at 60 to 90 days of age when the calf is eating 1 to 2 pounds of hay daily if the hay is fairly green. The calves usually do not gain as much during the first month or two on this ration as on whole milk but catch up later on.

The feeding of good-quality hay and a suitable grain mixture should begin at about 2 weeks of age.

Any one of the following feeding methods may be used up to the age of 6 months after the whole-milk starting period:

(1) Fresh skim milk may be gradually substituted for whole milk. Green, sun-cured hay will have to be used to supply the vitamins A and D lacking in skim milk, and a grain mixture to supply additional energy.

(2) The calf may be raised on a nurse cow—a hard milker, low producer, kicker, or one with some other trouble. It is necessary to use care to see that the calf does not get too much or too little milk. Hay and grain should be provided as usual at 2 weeks of age.

(3) The calf may be fed fresh buttermilk (pasteurized) or fresh whey, supplemented with legume hay and grain.

(4) Dried skim milk, dried buttermilk, or condensed buttermilk may be fed, mixed with water, plus the usual hay and grain supplements.

(5) Limited quantities of whole milk may be fed for the first 30, 50, or 60 days. Then grain or a calf meal may be completely substituted for milk. (Hay is fed as usual, of course.) It is sometimes difficult to grow calves on this ration, and growth will be retarded between 2 and 4 months of age. It should therefore not be used for raising undersized or weak calves. The grain mixture should have a

protein content of not less than 16 to 18 percent; it may consist of corn, oats, wheat bran, and linseed or cottonseed meal. Calf meals or calf starters used with this method of feeding consist of a mixture of grains plus protein from an animal source—dried skim milk (best source), dried buttermilk, soluble blood flour, ordinary blood meal, dry-rendered tankage, or fish meal. The calf meal may be supplemented with cod-liver oil.

In any feeding method, the calf should be fed all the green hay it will consume. In a grain mixture, corn may be replaced by barley, kafir, milo, or hominy feed; linseed meal by soybean meal, or half the linseed meal by cottonseed meal. Silage is not a suitable feed for dairy calves until after the age of 3 months, when it may be substituted for part of the hay. Pasturage is one of the best sources of roughage, but the calf fed on milk, hay, and grain will not make much use of pasture until after the age of 3 months.

After 6 months of age, milk and calf meals are discontinued and the heifer is fed entirely on roughage and pasture (all it will consume), supplemented with a little grain. She should be fed so that she makes good growth and is good sized and well fleshed, but not too fat, at the time of first calving. Liberal feeding of a heifer makes it possible for her to calve at an earlier age; scanty feeding delays the first breeding and calving. In the long run, it is probably most economical to feed heifers liberally so that they can be bred early, at 15 to 18 months, to calve at 24 to 27 months.

The young bull calf should be fed about like the young heifer calf, up to the age of 6 months, when he will need somewhat larger quantities of feed.

Data have recently been compiled on the size and weight of well-fed dairy calves at various ages, and on the rate of growth, and these are useful to check nutritional status.

As in the case of other animals, the nutritional requirements of dairy calves include carbohydrates, proteins, fats, minerals, and vitamins. A number of feeding standards have been proposed for energy (total digestible nutrients) and protein. The protein requirement depends in part on the quality or biological value of the protein; that provided by milk and milk products has the highest value for young calves. In practice it is well to provide more protein than the minimum requirement to allow a margin of safety. This is readily and economically done when legume hay is used.

Of the necessary minerals, sodium and chlorine must always be provided in the form of common salt—0.5 to 1.0 percent of the grain mixture, plus an available salt lick. The rations customarily used for calves supply enough calcium and phosphorus for normal growth, except that when the animals are fed largely on home-grown roughages in phosphorus-deficient areas it may be necessary to supplement the ration. Wheat bran, linseed meal, and bonemeal are rich in phosphorus. In goitrous regions it may be necessary to feed iodized salt to pregnant cows and heifers. A deficiency of iron, producing "salt sickness" or nutritional anemia of cattle, reported in some isolated regions, has been cured by administering very small amounts of iron and copper. Cobalt-deficient areas have been reported in Florida.

Of the vitamins, the only one that need give any great concern to the dairy cattleman is vitamin A. The requirement of young growing calves is considerable, and it may not be met with ordinary feeds used in practice. A deficiency results in such symptoms as slow growth, general weakness and scours, blindness, and susceptibility to pneumonia. The requirement for the young calf may be met by feeding whole milk from cows on pasture, supplements such as cod-liver oil, green alfalfa-leaf meal, garden carrots, or, for the older calf, good-quality green hay. It is especially important to provide vitamin A during the skim-milk feeding period. The conditions under which it will be necessary to supply vitamin A supplements have already been discussed.

VARIATIONS IN THE COMPOSITION OF MILK

The milk of different species of animals varies greatly in composition. For example, among various kinds of milk used for human food, that of the reindeer is most concentrated, containing only 63.3 percent of water as compared with about 90 in mare's milk (least concentrated); 10.3 percent of protein as compared with 1.05 to 1.63 in human milk (lowest in protein); 22.46 percent of fat as compared with 0.78 in mare's milk (lowest in fat); and 1.44 percent of minerals as compared with 0.18 to 0.21 in human milk (lowest in minerals). Human milk is highest in milk sugar, containing 6.79 to 6.98 percent as compared with 2.5 for reindeer's milk, which is lowest.

There are also considerable variations in the milk of a single species. In the case of cows, for example, the milk of the Guernsey contains 5.19 percent of fat and that of the Shorthorn 3.63; and there are breed variations in percentages of water, total solids, protein, milk sugar, and minerals. Again, there are variations in the milk of individual cows of the same breed in the same environment. Even in the same cow, morning milk is usually richer in fat than evening milk; and at the same milking, the first milk is different from the strippings, and that from one quarter of the udder may be different from that from another quarter. There are differences in successive phases of the lactation period, especially between colostrum milk and later milk.

In general, the relation between the percentage of fat and the percentage of protein in cows' milk is fairly constant. This is useful in practice because the fat percentage may be taken as a rough guide to the protein and energy values of milk and to the feed requirements for its production. Formulas have been worked out for calculating the protein and energy content of milk from the fat percentage.

The principal elements in the ash of cows' milk are potassium, calcium, sodium, magnesium, iron, phosphorus, chlorine, and sulfur. Among the elements found in smaller quantities are copper, zinc, aluminum, manganese, and iodine. Spectrographic analysis has shown traces of several other elements. Several of the minerals vary in quantity at various stages of the lactation period. Iodine is normally present in milk in varying quantities, and the iodine content can be increased by suitable feeding, but the method is not economical.

Flavors and odors are readily transferred to milk from the feed of the cow. It has been proved that even when cows only inhale garlic, the flavor and odor is transferred to milk through the lungs and the blood stream. Certain drugs and medicines given to cows have also been found in the milk.

UTILIZATION OF FEED ENERGY AND FEED PROTEIN IN MILK SECRETION

Data have been compiled by various workers to show how much of the energy in feeds is used for milk production. These serve as standards to indicate how much energy must be supplied in the feed to produce a given quantity of milk.

Several steps are involved in these calculations: (1) Either the digestible energy or the metabolizable energy in the feeds is calculated. The metabolizable energy is the part of the digestible energy that is actually usable in the organism. (2) From this is deducted the energy required for maintenance, growth or fattening, and gestation. The remainder is the amount available for milk production. (3) The total gross energy in the milk is calculated. (4) This is divided by the energy available for milk production. (5) The quotient is the "net efficiency of energy utilization"—in other words, the percentage relationship of the energy in the milk to the energy in the feed that is available for milk secretion. It is a somewhat indirect way of saying how much of this available energy actually goes into the milk.

Several variables are involved in all such data, and these tend to make them inaccurate. For example, the breed of the cow may possibly make a difference; also the composition of the milk, the stage of lactation, the level of feeding, and the completeness and balance of the ration. There are also uncertain and arbitrary assumptions—for example, in figuring the maintenance requirement, which must be deducted first. Moreover, the figures used are averages, whereas there is always a considerable variation between individual cows in the efficiency of feed utilization for milk secretion. Thus the averages can be used only as a general guide by the producer. He must take the individuality of his own cows into account.

According to the lowest of five different sets of calculations, the energy in milk is 58 percent of the available digestible energy in the feeds and 62 of the available metabolizable energy. According to the highest, it is 62 and 69.4 percent, respectively.

According to the lowest of 10 different standards, 5.456 pounds of total digestible nutrients are required daily for the maintenance of a 1,000-pound cow. The highest standard is 7.925 pounds (equivalent actually to about 7.5 pounds because of the method of calculation).

According to the lowest of eight different standards, 0.285 pound of total digestible nutrients is required to produce a pound of 4-percent milk. The highest standard gives 0.343 pound. There are similar variations in the standards for milk with other percentages of fat.

In figuring the utilization of protein in milk secretion there are many uncertainties and unanswered questions. For example: When 50 or 60 percent of a feed protein is said to be digestible it is possible that 90 to 100 percent of it is actually digested, but 40 to 50 percent eventually appears as nitrogen-containing products in the feces, so that this percentage is counted as having passed through the animal without being digested. Again, only 10 of the 20-odd amino acids must be supplied in the diet of the rat for maintenance and growth;

it can presumably make the others in its own body, and it is assumed that the situation is about the same for other animals. But is it? And even if the other amino acids can be made in the body of the cow, would it be better to supply them in the diet for economy in milk production? Certain amino acids are probably needed in relatively large quantities for milk secretion; but are they needed in anything like as large quantities for body maintenance?

There is very little reliable information on the amino acid composition of the protein mixtures in feeds. It has been noted that the utilization of feed proteins in milk secretion seems to vary with their content of the amino acid lysine, and on the basis of the lysine content of various feeds the feeds might be graded in the following order: Blood meal, skim milk, meat meal, beans, peas, soybeans, peanut cake, alfalfa, wheat bran, cottonseed meal, linseed meal, oats, red clover hay, wheat, corn, barley, oat straw, beet pulp. In another experiment, certain sources of protein were rated as follows in biological value: (1) Fresh and dried spring grass, grass silage from summer grass, low-temperature dried blood meal; (2) fresh and dried autumn grass, bean meal, and pea meal; (3) decorticated peanut cake, decorticated peanut cake and flake maize; (4) linseed cake, linseed meal. Such analyses at present cannot be considered as exact; they merely give an idea of how proteins may vary in feeding value. In certain protein-balance experiments it was found that when milk proteins were fed with a basal ration of corn stover and starch, the cows laid on protein reserves in their bodies, but when the same quantity of wheat or corn proteins were fed the cows actually "milked flesh off their bodies" to maintain production.

It has been suggested that the biological value of feed proteins for milk secretion may be safely assumed to be not less than 50 percent, and that the cow should receive an amount of digestible protein equivalent to twice the protein secreted in the milk.

Several calculations have been made of the amount of protein needed for maintenance and the efficiency of the utilization of protein in milk secretion. Some controversy at present centers around the question of whether it is necessary to feed 0.7 pound of protein daily per 1,000 pounds of live weight for the maintenance of a cow, and how much should be fed in addition for milk production. The latter figure varies in different standards from 1.25 times the protein in the milk, which would be a low-protein level of feeding, to 2 times, which would be a high-protein level. The inadequacy of a level as low as 0.5 pound per 1,000 pounds for maintenance and 1.25 times the protein in the milk has been clearly demonstrated in one experiment, at least for the cows used in that experiment. It was also demonstrated that cows react very differently to a low-protein level of feeding, and with some it may prove disastrous.

THE VITAMINS IN MILK AND IN MILK PRODUCTION

In the cow's body the yellow carotene from plant foods is converted into colorless vitamin A. Both unconverted carotene and the colorless vitamin are transferred to the milk. The color of the butterfat depends on the amount of carotene it contains. Some breeds of cows convert carotene into vitamin A more efficiently than others. On the same diet their butterfat would be less yellow than that of the less efficient converters. This might simply mean that it had more actual vitamin A and less unconverted carotene. In general, however, the color of butterfat is an indication of its vitamin A potency.

The amount of carotene (or of vitamin A) in the cow's ration has little or no effect on the milk yield, but it determines the vitamin A potency of the butterfat. When the carotene received by the cow is less than a certain amount the calves born are abnormal; when it is reduced still more the cow herself becomes night blind; when the cow's milk has less than a certain vitamin A potency the nursing calf becomes night blind.

In general, the more carotene there is in the cow's ration the greater will be the vitamin A potency of the butterfat—and, of course, the milk containing the butterfat. Grains including even yellow corn - are a poor source of carotene. The cow usually gets 90 percent of her carotene supply from roughage. Furnishing an adequate or generous amount of carotene, therefore, is a matter of feeding the right kind of roughage. A ration in which poor timothy hay is the sole roughage may result in butterfat that has only one-fiftieth as much carotene as one in which the roughage is high-quality alfalfa hay.

The vitamin A potency of milk and butterfat then can be directly controlled by diet. To what extent this should be done in the case of milk for human consumption remains to be seen. For suckling calves the milk should certainly have enough vitamin A potency to permit normal growth.

During lactation an animal requires more of the B vitamins (particularly B_1 and G) than at other times. Its health, the capacity to lactate, the yield of milk, and the composition of the milk are all affected by the supply of these vitamins available. A deficiency of vitamin B_1 leads to reduced food consumption, and this in itself would affect the yield and probably the protein content of milk. Suckling young may suffer from severe deficiency diseases when the mothers are on diets low in vitamin B_1.

Whether the B vitamins need to be supplied in the ration of the dairy cow, either for her own use or for secretion in her milk, is another matter. There is evidence that these animals manufacture some of these vitamins in their paunch. With human beings and rats there is no doubt about the need for vitamin B_1 in the diet. And the concentration of vitamin G in cow's milk as in human milk—may be increased 50 to 75 percent by increasing the vitamin G in the diet.

The cow makes vitamin C in her body and does not require it in her diet. In fact, if she does consume it in food, it may be destroyed by oxidation in the rumen or first stomach. Along with the vitamin C in foods there is often an enzyme that hastens the oxidation of vitamin C; and after oxidation has proceeded beyond a certain point the vitamin is no longer active. A little copper speeds up the action of this enzyme a great deal. After milk is drawn from the cow the vitamin C it contains soon begins to oxidize. Pasteurization hastens the process, and pasteurizing in copper vessels speeds it up still more. Heating for half a minute at 170° F., however, will destroy the enzyme, and copper is then not so damaging to the vitamin C in the milk.

The vitamin C content of human milk is considerably higher than that of cows' milk and may be increased by feeding large doses of vitamin C. There is some evidence that the content in cows' milk may be increased by injections of vitamin C under the skin.

Symptoms of vitamin D deficiency in cattle may be produced experimentally by keeping the animals in the dark on a vitamin D-deficient ration. These conditions would seldom occur in practice. The requirements of the animal are met by ordinary rations and a little exposure to sunlight. An increase of vitamin D in the feed or exposure to sunlight increases the vitamin D content of the milk. Milk fat produced in summer may contain nine times as much vitamin D as that produced in winter.

GLANDS, HORMONES, AND BLOOD CONSTITUENTS—THEIR RELATION TO MILK SECRETION

Glands and Hormones

In the attempt to unravel the mysteries of lactation, some experimental work has been done with hormones secreted by various glands in the body.

Milk is secreted by the mammary gland (the udder or breast). What part do hormones play in the development of this gland?

Experiments show that the mammary gland does not develop fully in an animal without ovaries. In females deprived of their ovaries (spayed), however, injections of estrin (a hormone secreted in the sex organs during heat) stimulates an incomplete development of the mammary gland. The gland can be stimulated to still further development by injections of estrin and the yellow-body hormone (also secreted in the sex organs during heat). But the mammary gland will not develop with either or both these injections if the pituitary gland (located in the head) has been removed from the animal. Pituitary extracts will stimulate some development of the mammary gland in females without ovaries. Thus apparently the ovaries, the pituitary gland, and the two sex hormones mentioned all act together in the full development of the mammary gland.

What part is played by hormones in the secretion of milk as distinct from the development of the mammary gland?

Animals can produce milk even without ovaries, but milk is not secreted in the absence of the pituitary gland unless pituitary extracts are given. Some milk secretion can be stimulated merely by manipulating the nipples if the pituitary gland is intact. When the uterus is distended (naturally in pregnancy, or artificially by inserting foreign material) milk secretion may decrease or stop. Large amounts of estrin will also inhibit milk secretion. This may account for the definite decrease of milk yield when heat, with its accompanying flow of estrin, occurs during lactation. The natural decline in milk yield that occurs as the heat cycle is resumed cannot be prevented by removal of the ovaries.

An extract called prolactin, recently made from the pituitary gland, will stimulate milk production in a normal animal provided its own pituitary gland is intact. When an animal's pituitary gland is removed every other endocrine gland in the body wastes away, including the adrenal gland located near the kidney. Prolactin will still stimulate milk secretion after the pituitary gland is removed provided extracts from the adrenal gland are given at the same time; but injections of common salt can be substituted for adrenal extracts with the same results. Apparently, then, the adrenal gland is not essential for milk secretion. Experiments prove that the thyroid gland is not necessary either.

The pituitary gland has powerful effects on many body functions. Its secretions are made of protein, and the proteins in the diet may have much to do with their formation. One of these secretions is a hormone that stimulates the sex glands (gonads). In the past few years, unidentified substances that also stimulate the gonads when injected into an animal have been extracted from the green leaves of young plants. Does this have some connection with the observed stimulating effect of young pasture grass on milk production?

Pituitary extracts cannot yet be used safely for such purposes as stimulating the production of milk, but the experimental work so far is highly suggestive of possibilities for the future.

Blood Constituents

Among the constituents of milk produced in the mammary gland are lactose (milk sugar), proteins, and certain easily evaporated fatty acids. What materials in the blood stream are used to make these substances and how does the level of the material in the blood affect milk secretion?

The sugar in blood is glucose. Experiments show that the mammary gland does take glucose out of the blood. They also show that mammary-gland tissues can readily make lactose if supplied with glucose. Chemically, this would require a complex and far-reaching rearrangement of some of the glucose molecules. Other experiments indicate that both glucose and lactic acid may be taken from the blood to make the lactose in milk. Reducing severely the amount of glucose in the blood reduces the amount of lactose in the milk, but ordinary reductions in the amount of carbohydrate in the cow's diet do not. Instead, they reduce the milk yield and the amount of protein in the milk.

Lactoglobulin, one of the proteins in milk, is identical with serum globulin in blood, and is believed to come directly from that source. Two other proteins, lactalbumin and casein, are believed to be made in the mammary gland from amino acids and polypeptides (simple combinations of amino acids) in the blood stream. The evidence indicates that amino acids and polypeptides are taken from the blood stream and used to make milk proteins. Some workers report that this is also true with serum globulin. A change in the quantity or quality of proteins in the diet may affect not only the secretion of protein in milk but also the amount of milk secreted as a whole.

All the fatty acids in milk except those that are easily evaporated could come directly from the feed and the blood. The easily evaporated fatty acids are made in the mammary gland, but their origin is unknown. Nor is it known whether the mammary gland makes fat out of carbohydrate, though this does occur elsewhere in the cow's body. The percentage of fat in milk bears a fairly constant relation to the percentage of protein, and a diet inadequate in protein reduces the fat content of the milk as well as the protein content and the total yield of milk.

MILK IN NUTRITIONAL RESEARCH—A SKETCH OF PRO

In the days when chemists were analyzing foods i eins, fats, and carbohydrates, they began to make up experim s of these substances for animals (rats and mice) in the labo Curiously enough, "although animals can live on milk alone," wrote Bunge, one of the German experimenters, "yet if all the [necessary] constituents of milk be mixed together, the animals rapidly die." Evidently there was something in milk besides proteins, fats, and carbohvdrates that was essential to life.

This "something" appeared on further experiment to be minerals. But even when an artificial diet containing milk minerals was supplied, the animals failed to live—as the Englishman Hopkins proved. There was still something else necessary to life. This time it proved to be vitamins.

For six or more decades now, research workers have been making up synthetic diets for animals containing everything known at the time to be necessary for life, growth, and health, and comparing these diets with natural foods. Each time the artificial diet, prepared according to the best available knowledge, proved to lack some necessary substance that must have been present in the natural food; and the lack of the substance often produced definite symptoms of disease or abnormality. Then the search began for this substance through further, more careful experiments.

By such methods the vitamins were discovered one by one.

The work was enormously stimulated when it was discovered, in 1885, that human beriberi, prevalent in the Japanese Navy, could be cured mainly by feeding the sailors barley instead of polished rice. Experiments with pigeons showed that polishing or refining the rice took out a mysterious life substance, a vitamin. Experimental work showed that this substance was necessary for growth as well as the prevention of beriberi. Later it was found that there were two separate vitamins, one preventing beriberi and promoting growth (vitamin B_1) and another, with different characteristics, also promoting growth (vitamin G).

Eventually two other vitamins were found in this original "vitamin B." One was vitamin B_6, isolated in crystalline form in 1938. Lack of this vitamin produced a skin disease in chicks. Another was nicotinic acid, which cured blacktongue in dogs (blacktongue being the canine form of pellagra). And there may be still other vitamins in this original "vitamin B" that cured beriberi.

There are similar stories connected with the discovery of vitamins A, C, D, and E. At least eight vitamins are now known. They are no longer unseen mysterious substances. Within the last few years it has been possible to see, touch, weigh them, and finally to make some of them synthetically in the laboratory. In our time, probably, new vitamins will be discovered.

Some of this work was done with milk, and the list of known substances in milk steadily increased. Discovering what milk lacked also advanced knowledge of nutrition. For instance, knowledge of iron requirements was advanced by finding that milk lacks sufficient iron to support the young animal beyond a certain stage of growth.

NUTRITIVE REQUIREMENTS OF SWINE

Swine are economical converters of feed into body tissue, growing rapidly to market weight at 7 to 10 months of age and breeding when younger than most farm animals. Their ration is made up largely of concentrates with a small proportion of roughage. Until well within the present century it was thought that practically all they needed were carbohydrates and fats to supply energy, with enough protein to build and maintain body tissues. Early work on nutritive requirements was based on this viewpoint. Then it was found that proteins are different, and that some—the zein of corn, for example—lack amino acids essential to the animal body. Finally, a growing list of minerals and vitamins came along to complicate the picture.

The earlier interest in energy requirements has been largely submerged in the United States by the general use of self-feeders for hogs. Instead, the problem now is to find the feed mixtures that will promote the most rapid and economical gains in weight, and this is to no small extent a problem of proteins, minerals, and vitamins. Energy standards are nevertheless very useful in measuring the effects of improvements in rations.

In 1917 Armsby concluded that the net energy required for maintenance by swine was 1,199 calories a day per 100 pounds of live weight. Different formulas or equations have been devised since then for figuring maintenance requirements, and several tables have been worked out. After maintenance requirements are met there are additional requirements for growth and fattening. Total energy requirements, including maintenance, growth, and fattening, have been expressed in a number of standards. It is difficult to make such standards precise for various reasons, and most of them permit a wide latitude in feed allowances.

It has been demonstrated that the lean tissue of the carcass can be maintained or even increased by restriction of the energy intake. Further experimental work with restricted diets might result in better information on dietary balance and economical feeding.

The problem of protein requirements is of more practical concern that that of energy requirements. The discovery that a diet of corn alone supplies too little protein, qualitatively and quantitatively, has been of major importance in hog feeding. Since a good deal of the protein supplement in the hog's ration must be purchased, there is a powerful reason to meet protein requirements economically.

The amount of protein actually used in the hog's body can be determined rather accurately; so can the protein content of different feeds. But this is only the first step. Not all the protein in a given feedstuff is digestible—only 60 to 90 percent of it, for most common feeds. And not all the digestible protein is biologically usable in building tissue. Many proteins have a biological value not much over 50 percent. For example, according to one study, a growing pig weighing 100 pounds required 0.029 pound of protein for maintenance and 0.103 pound for growth, or a total of 0.132 pound daily. In the ration of corn, middlings, and tankage, only about half of the total protein was biologically usable—so twice as much protein would have to be fed as the hog required. Again, of the total protein fed, only two-thirds would be digestible—so half again as much would have to be added to take care of this factor. Thus to meet a requirement of 0.132 pound of protein, the farmer would have to feed 0.132×2×1½, or 0.396 pound.

As in the case of energy, various standards for protein requirements have been worked out by different investigators in Europe and the United States. Some are low, some medium, some high. Experimental work indicating that the rate of gain of growing pigs increases with a larger protein content in the diet suggests that medium-high standards should be used in general.

The body of a 225-pound pig contains 5 pounds of some 13 minerals. Calcium and phosphorus make up more than 2⅔ pounds of the total, and it is imperative that they be supplied in adequate amounts; but the requirements can ordinarily be met by proper selection of feeds. In goitrous areas it is necessary to supply iodine, especially to the pregnant sow. Suckling pigs that do not have access to some source of iron and copper besides the mother's milk develop anemia unless those minerals are supplied in small amounts. Mineral mixtures that will meet a possible deficiency of various elements can be made at home and fed at the rate of 1 or 2 pounds to 100 pounds of feed.

Experimental work so far shows that swine need vitamins A and D, riboflavin, nicotinic acid, two other fractions of the vitamin B complex, and probably vitamin B_1. Lack of vitamin A will produce night blindness as well as retarded growth and other physical symptoms, including impaired reproduction. A suggested minimum requirement is 1 to 1.3 milligrams of carotene or 0.3 milligram of vitamin A per 100 pounds of body weight. Green feeds and yellow corn are natural sources of carotene. Lack of vitamin D produces rickets and poor growth. Sunshine will prevent this condition; sun-cured alfalfa is a useful source of vitamin D in winter. Much work needs to be done before the requirements of hogs for the B vitamins are known. Common feeds that have high protective value in hog rations include skim milk, buttermilk, whey, tankage, meat and fish meals, and leafy forages.

With self-feeding, hogs need plenty of water at all times if they are to consume enough dry feed to make the most rapid growth.

PRACTICES IN SWINE FEEDING

The hog industry in the United States is based on corn, but hogs can probably make use of more different feeds than any other farm animal. Production is carried on in all of the 48 States. There are great differences in the feeds used, and in methods of feeding and management, between the four major regions—the Corn Belt, the South, the Atlantic coast, and the West.

Among the feeds used, the grains supply carbohydrates for energy and fattening (the hog is unusually efficient in converting sugar and starch into body fat). All of the grains need to be supplemented with other feeds supplying proteins, minerals, and vitamins for a well-balanced diet and economical gains. Yellow corn has a higher vitamin A value than white corn.

Compared with corn as a standard, the feeding value of the other grains runs about as follows: Grain sorghums, 10 percent less than corn; wheat (whole, ground), 5 percent more than corn, with less protein supplement required (wheat byproducts may profitably replace one-third of the corn in the ration with good results); barley, 8 to 26 percent less than corn, depending on the weight of the barley; oats (good quality, ground), considered equal to corn up to one-third of the ration; rye, 10 percent less than corn—should not make up more than half the ration; rice bran, 10 percent less than corn—should not make up more than half the ration; brewers' rice, equal to corn—produces very firm pork.

Molasses is considered to have 10 percent less fattening value than corn; it should not make up more than one-fifth of the ration. Sweetpotatoes may be fed or grazed in combination with grain; they have one-fourth to one-fifth the fattening value of grain. Potatoes should be cooked before being fed; they have about a third to a fourth the fattening value of grain, and should not replace more than half the grain in the ration. Root crops are 80 to 90 percent water and have little feeding value.

Soft pork, which is produced by feeds high in oil, usually suffers a cut of 10 to 25 percent in market price. The common softening feeds are peanuts, soybeans, mast (acorns and nuts), rice bran, rice polish, and corn-germ meal. Young pigs fed on a diet that produces soft pork may be hardened off later on grain during the fattening period.

Wet brewers' grains have a low nutritive value, though they may be an economical feed under some circumstances. Distillery slop, properly supplemented, may also be used.

Grains and other energy feeds must be supplemented with protein feeds, home-grown or purchased, for the best results in growth and fattening. Skim milk or buttermilk is worth about half and whey about one-fourth the price of a bushel of corn in hog feeding. After weaning, 4 to 5 parts of skim milk or buttermilk may be fed to 1 part of corn, the proportion of milk being gradually reduced to 1 or 1½ parts at 150 pounds body weight. The value of digester tankages, from the packing industry, should be figured on the basis of their protein content, which varies from 35 to 65 percent, according to the grade of the product. Tankage furnishes minerals as well as protein. Fish meals are similar to tankage in feeding value, and in addition are a source of vitamins A and D. Shrimp meal (shrimp bran) is a good protein supplement. Cottonseed meal is economical but should not be fed too heavily. Like linseed meal, it is best fed in a mixture with tankage or fish meal, and should be supplemented with a feed rich in vitamin A. Peanut meal is good but must be supplemented with feeds rich in calcium and vitamins A and D. Soybean meal (oil-extracted) is excellent and may even be used as the sole protein concentrate for hogs weighing over 100 pounds. Alfalfa meal is fairly rich in minerals and vitamins A and D, though it is too bulky to be fed as the only protein concentrate. Alfalfa-leaf meal is higher in protein and lower in crude fiber. Protein feeds may be mixed with grain or fed as a separate protein mixture in a self-feeder that allows the hogs free choice of different feeds.

In selecting the hog ration as a whole, it is well to avoid any combination that contains over 5, or at the most 7 to 8 percent, of crude fiber. Generally, the ration should contain 18 to 20 percent of protein for pigs weighing 35 to 100 pounds; 15 percent for those weighing 100 to 150 pounds; about 12 percent for those weighing 150 to 225 pounds. The choice of individual feedstuffs depends largely on local conditions and comparative costs. If the ration is well balanced, it should furnish enough minerals, especially if pasture, legume hays, and yellow corn are used. In the dry-lot, a mineral mixture may be fed if necessary.

Any one or any combination of four methods of feeding may be used—hand feeding, self-feeding, limited feeding, or hogging-down crops. In hand feeding the hogs are usually fed twice daily, and they must accept the feed mixture as a whole. In self-feeding, different feeds are usually placed in separate compartments. The hog balances its own ration, eats less at a time but more often, and gains economically and rapidly. In limited feeding, the hogs are fed less than a full daily ration; the method requires more labor but may be worth while under certain circumstances since it results in economical gains. For hogging down, corn is the principal crop used, or peanuts, sweetpotatoes, and root crops in the South; usually a short period of dry-lot feeding is required to finish the animals.

Good pasture may save 15 percent of the grain required; it speeds up the rate of gain compared with dry-lot feeding and helps to control parasites if pastures are rotated. The plants most commonly used for permanent pastures are alfalfa, red clover, alsike clover, white clover, bluegrass, orchard grass, lespedeza, and carpet grass; for temporary pastures, rape, rye, oats, wheat, soybeans, cowpeas, and field peas. Good legume pasture may cut 60 to 70 percent off the amount of protein supplement required in the ration.

Suckling pigs may be fed protein supplements beginning at 3 weeks of age. Following weaning, the ration must be high in protein for good growth. After the early period of rapid growth, the proportion of protein is cut down and that of fattening feeds is increased. Fattening pigs on full feed require about 1 pound of feed daily for every 20 pounds of live weight up to 100 pounds. From 100 to 200 pounds they require about 1 pound of feed daily for every 25 pounds of live weight. About 1 pound of protein concentrate is required to 9 pounds of corn. From 35 pounds weaning weight to 200 pounds market weight, a hog will need 660 pounds of feed—594 of corn and 66 of protein concentrate.

Breeding pigs should be fed to get maximum growth without too much fat. Gilts are usually bred at 8 to 8½ months of age, to farrow the first litter at 1 year. During the gestation period, additional protein should be fed to the sow to meet the needs of the growing embryos. In fact, a protein reserve should be built up in her body for the subsequent drain of lactation. A considerable proportion of animal protein, and a mineral mixture, should be included in the ration. A sow suckling a litter requires feeds that will furnish a heavy milk flow.

FEEDING PROBLEMS WITH SHEEP

Most of the experimental work on sheep feeding has been in the form of practical feeding trials. There has been little research on specific requirements for proteins, minerals, and vitamins. The need for economy in sheep feeding, which is becoming more urgent, will almost certainly throw greater emphasis on a closer study of nutritive needs.

The mineral deficiencies most likely to show up in sheep feeding are those of calcium, phosphorus, or iodine. Each of these can readily be supplied as a mineral supplement if necessary. The vitamin that is most likely to be deficient—and this especially when sheep are fed on poor-quality roughage in the winter—is vitamin A, which can be supplied as carotene by feeding plenty of early-cut well-cured hay. Sheep need plenty of fresh water, and they consume relatively more salt than cattle.

Good pasture and good roughage are the backbone of sheep feeding. In some regions, flocks can thrive the year round without any grain. Under many conditions, it is advisable or necessary to use some concentrates. Alfalfa hay is an outstandingly good feed. Much timothy is used, but it is very important that it be cut young. Silage or roots can be fed with hay. Dependence on pasture or range alone often presents problems of nutritional deficiencies, because of the nature of the soil or plants, which require correction by suitable supplements such as phosphorus or trace mineral elements.

In the East, and in irrigated and dry-farming areas of the West, sheep are kept in farm flocks of 20 to 300 head. In the fall the breeding sheep can usually get much of their feed from stubble and stalk fields, followed by clover and grass pastures, rye or wheat pastures (with concentrates), or, in the South, velvetbeans. Most of the feed will come from pasture during late spring, summer, and early fall. Suggested winter dry-lot combinations given in pounds per head daily, for pregnant ewes weighing 110 to 140 pounds, are (in pounds): (1) Alfalfa or soybean hay, 3; corn silage, 2; shelled corn, one-half; (2) alfalfa hay, 3; corn stover, 2; (3) alfalfa or clover hay, 3½; corn silage, 2; (4) oat straw, 2; corn silage, 2; shelled corn, three-fourths; linseed meal, one-fourth. Cottonseed meal as a protein concentrate is best used in limited quantities—not over one-fourth of a pound per head daily—with other feeds.

In the West, most sheep are in range bands—usually 1,000 to 2,000 head. They subsist largely on natural forage, but snow, drought, and overgrazing make it necessary at times to feed hay and concentrates. Alfalfa hay may be fed alone, or native hay may be used with a protein concentrate such as cottonseed cake. Suggested rations for range ewes weighing 110 to 140 pounds are (in pounds): Before lambing—alfalfa hay, 4; whole oats, one-half; after lambing—alfalfa hay, 5; corn silage, 2½; whole oats, three-fourths. Under some conditions, ewes should be fed grain for 3 or 4 weeks before lambing, and corn silage or beet pulp may be used before and after lambing.

Rams on farm or range may be fed like ewes, in somewhat larger quantities. They do not need to be fattened, but they should have feed of rather high quality just before and during the breeding season.

Flushing (extra feeding) of ewes to increase the number of twins and extra feeding of lambs through the suckling period are profitable wherever they can be done economically. Good pasture is best for this; grain may be used as a supplemental feed. The ewe must be fed to gain at least a pound a week during the breeding season.

Where pastures and ranges are good enough, lambs can be "milk-fed" to be ready for market at weaning time. A considerable part of the lamb crop, however, must be fattened after weaning. Corn and alfalfa hay are the preferred feeds for fattening lambs. Other feeds used where they are economical include barley; sorghum grains; oats; wheat; rye; cottonseed or linseed meal; silage of corn, corn and soybeans, sorghum, pea vines, peas and oats; and wet beet pulp, turnips, mangels, rutabagas, beet tops, cabbage, and cull potatoes. A suggested fattening ration consists of 7 parts of corn and 1 part of cottonseed meal by weight, plus corn silage and clover hay. This is fed at the rate of about 1⅓ pounds each of concentrates, silage, and hay per head daily for lambs entering the feed lot at 60 to 65 pounds and finishing in 80 to 90 days at 90 to 95 pounds.

Hothouse lambs are lambs produced out of season—born in fall or early winter, ready for market at 2 to 4 months of age (about 40 to 60 pounds) while they are still suckling. The mothers of these lambs must be exceptionally well fed for milk production. A suggested ration consists of 5 parts corn, 2 parts oats, 2 parts wheat bran, and 1 part linseed meal by weight, plus corn silage and well-cured second-cutting alfalfa or their equivalent. This is fed at the rate of about 1 to 1½ pounds of the concentrate mixture, 2 to 3 pounds of corn silage, and 2 to 3 pounds of alfalfa hay per head daily. The lambs should be fed in a creep beginning at about 2 weeks of age. The same combination of feeds may be used, but the corn should be cracked, the oats crushed, the alfalfa bright and leafy, and the silage the best available. They may be fed as much as they will clean up each day.

Poisonous plants are a serious problem on the range where close herding is practiced so that the sheep clean up all vegetation as they go along. The principal poisonous range plants are the death camas, locoes, and lupines (pods and seeds). Wild cherries, certain milkweeds, the rayless goldenrod, the Colorado rubber plant, the "coffee bean" of Texas, and the sneezeweed have caused losses. There is as yet no practical method of eradicating most of these plants.

FEEDING PROBLEMS WITH GOATS

Goats are very fond of browse (leaves, twigs, and weeds), though they also relish good grass. Otherwise they eat about the same feeds as sheep. They should have free access to salt. In some cases, supplements of calcium, phosphorus, or iodine may be necessary.

Angora goats are fed on browse, weeds, grass, and, in winter, evergreen brush (except cedar and conifers). In winter, it may be necessary to use such supplementary feeds as hay, kale, rape, corn, milo, feterita, oats, or other grains. If the winter roughage is low in protein, some protein-rich concentrate should be added. A suggested allowance when the animals must be fed entirely on stored feeds is one-fourth to one-half pound of good concentrates and 3 to 4 pounds of good roughage.

The feed required for one cow will be enough for six or eight goats, but the milk goat should be proportionately as well fed as the dairy cow. According to tests, a pound of grain a day will be required for each quart of milk produced per day as an average throughout the period of lactation. A doe that is pastured as much as possible may require some 500 pounds of choice to good legume hay and 450 pounds of grain a year. A suggested winter ration for does in milk consists (in pounds) of alfalfa or clover hay, 2; corn silage or roots, 1½; grain mixture, 1 to 2. A good grain mixture might be made (in pounds) of corn, 100; oats, 100; wheat bran, 50; linseed meal, 25. A doe on good pasture may be given 1 to 1½ pounds of grain mixture a day.

Other feeds used for goats are timothy hay (early-cut), corn stover, corn and sorghum silage, mangel-wurzels, carrots, rutabagas, parsnips, turnips, beet pulp, barley, cottonseed meal or cake, brewers' grains, corn bran, gluten feed.

Young does should be kept in good growing condition on browse and pasture, supplemented with a little grain if necessary. A suggested winter ration consists of grain, 1 pound, silage or roots, 1 to 1½ pounds, and all the hay or other roughage the doe will consume. A kid to be raised for milking should have 1½ to 2 pounds of milk a day besides good pasture or roughage and a little grain. Whole cows' milk may be used, or even skim milk (2 to 3 pounds a day, supplemented with choice alfalfa hay and grain) if the change from whole milk to skim milk is made gradually. At about 10 weeks of age, the milk may be largely replaced by good alfalfa hay and mixed grain.

Bucks on good pasture need no grain. In winter they may be fed on legume hay and corn stover, with silage or root crops and enough grain to keep them in good condition.

In all but a few municipalities, goat meat goes into the regular trade as mutton or lamb. For the best finish, such fattening feeds as corn, barley, or sorghum grains should be used, together with good forage. A suggested ration consists (in pounds) of alfalfa hay, 2; corn silage or roots, 1½; grain mixture, 1 to 2.

NUTRITION OF HORSES AND MULES

The feeding requirements of horses, like those of other livestock, call for adequate amounts of energy, protein, minerals, and vitamins. Some feeding standards for energy and protein have been worked out according to type and weight of the animal and the work it does. Those given by Morrison range from 5,600 calories of net energy and 0.6 pound of digestible protein a day for a mature idle horse weighing 1,000 pounds to 24,100 calories and 2.4 pounds of digestible protein for a mature horse weighing 1,800 pounds at hard work. Morrison also gives standards for brood mares nursing foals and for draft colts after weaning. Relatively, the protein requirement is greatest for young growing colts and pregnant and nursing mares. The energy requirement of the growing colt is also relatively high. For mature animals, the energy requirement is determined by the size of the animal, the kind and amount of work performed, and individual characteristics.

The mineral requirements are highest for calcium and phosphorus, as with other animals; and they are relatively greater during the period of growth and in pregnancy and lactation. There is no clear experimental evidence to indicate the quantitative requirements for those two minerals at any age, but according to analyses of carcasses, Percheron horses weighing between 400 and 1,600 pounds need 13.5 grams of calcium and 13.6 grams of phosphorus a day. Lack of sufficient calcium or phosphorus produces the same kinds of nutritional diseases and abnormalities that occur in other animals. Horses must have common salt daily, and the amount needed is highest when they are at heavy labor, particularly during warm weather. In the so-called goiter belt of the United States it is advisable to use an iodine supplement, especially for pregnant brood mares and colts.

Little is known about the vitamin requirements of horses, but they are probably similar to those of other animals. Horses get night blindness from a deficiency of vitamin A.

When it comes to practical feeding, the results of experience may be added to the very limited amount of experimental work in setting up standards and formulating rations.

Many people consider oats the best concentrate feed for horses, but there is evidence that other grains may be as good. Corn is most commonly fed in the Corn Belt; it is low in certain proteins, minerals, and some vitamins, but these may be supplied by alfalfa and other legume hays. Barley is used in many parts of the West; it should be rolled, crushed, or coarsely ground. Wheat bran is a favorite feed; a small amount will improve almost any ration, and it is often used as a laxative mash. Old-process linseed meal in amounts of ½ to 1 pound per head daily may be fed as a laxative and conditioner. Choice cottonseed meal may be used as a protein supplement in limited quantities. Wheat, rye, rice, and some leguminous seeds are sometimes fed; all should be rolled, crushed, or ground.

Since the stomach of the horse is comparatively small and the energy requirements of the animal are relatively high, roughage often should be limited and of good quality, especially during periods of hard labor. Timothy hay is popular but not so valuable as legume hay. Johnson grass, used in the South, compares favorably with timothy. First-cutting alfalfa is excellent but should be restricted to 1 pound or less daily to 100 pounds of live weight. Bright red clover hay is a good roughage and may be mixed with timothy. Soybean hay is slightly laxative; it should be fed in somewhat limited quantities. Oats, barley, and wheat, cut before maturity and properly cured, make good hay that includes some grain. Prairie hay and hays from cowpeas, millet, and sorghum are used in some sections. Cheap, low-quality roughages such as corn fodder and straw may be economical feeds under certain conditions, if combined with good roughage and concentrates. Corn silage should be considered as a supplement or appetizer. Good alfalfa silage might well be used more than it is. Pasture alone does not furnish enough nutrients for steady work, but it may be used to maintain idle stock, and it is always valuable for minerals and vitamins.

A mature horse drinks 10 to 12 gallons of water a day. Regularity and frequency of watering are important.

Where there is a known or probable mineral deficiency, a mineral supplement should be fed, especially for young stock. Dried milk products, steamed bonemeal, or dicalcium phosphate may be used for a phosphorus deficiency; ground limestone or oystershell flour for a calcium deficiency. A calcium supplement alone should not be added to rations low in phosphorus. Mineral supplements may be mixed with common salt.

A general guide for quantity of feed is to allow 1¼ to 1⅓ pounds of grain with 1 pound of hay per 100 pounds of live weight for horses at heavy work; 1 pound of grain and 1 to 1¼ pounds of hay at light work. Grain for horses at work is usually given in equal portions morning, noon, and night; most of the hay at night, some in the morning, very little at noon. Overfeeding is more common than underfeeding when horses are working irregularly.

An idle horse may be carried almost entirely on roughage. During the winter, it should not be allowed to become either fat or thin. A horse wintered in the open with a shed for protection is likely to be in better condition in the spring than one confined to a stable without exercise. A period of 2 to 4 weeks on a gradually increasing quantity of grain and good hay is usually required to fit the idle horse for heavy spring work. The brood mare needs special handling after parturition. The foal will start to take dry grain at a month or so of age. It should be eating about 4 pounds of grain a day at weaning age (6 months), as well as grass or legume roughage, and from then until 12 months of age it should have good rations with plenty of protein, minerals, and vitamins. Grain may be limited if roughage is good.

PRACTICAL NUTRITIVE REQUIREMENTS OF POULTRY

The egg-laying capacity of a hen is determined largely by her inheritance, but the number of eggs she actually lays is determined by the kind and quantity of food she eats. The maintenance requirement of the hen depends on her size; for a 3½-pound White Leghorn pullet it is 0.134 to 0.148 pound of feed a day, and for a 5½-pound Rhode Island Red it is 0.205 to 0.227 pound. After growth and maintenance requirements have been met, it takes 0.09 pound of feed a day, on the average, to produce a 2-ounce egg. A White Leghorn pullet will consume a total of 7.7 to 8.7 pounds of feed per dozen eggs if she lays 100 eggs a year, but only 4.4 to 4.9 pounds per dozen if she lays 200 eggs. Hence the economic importance of high production.

Grain alone will not support high egg production; it does not contain enough of the right kinds of proteins. The feed consumed each day should furnish not less than 12.5 grams of protein of good quality for high production, and not less than 20 percent of the protein should be of animal origin (from milk, meat, or fish products). It is safe to rely on a protein content of 16 to 17 percent of the diet.

A chicken laying 200 eggs a year puts into them about 400 grams of calcium—13 to 15 times as much as there is in her body. Thus if the diet contains too little calcium, egg laying ceases. The percentage of calcium to feed in the diet depends on the number of eggs laid, the quantity of feed consumed, and the percentage of phosphorus fed.

About 0.5 percent of salt should be added to the average diet. Many feed mixtures do not contain enough manganese, and this may be added to the salt at the rate of 1.7 parts of anhydrous manganous sulfate, or 2.5 parts of manganous sulfate tetrahydrate, to 100 parts of salt.

If the eggs are to be used for hatching, the following quantities of vitamins per pound of feed should be used: Vitamin A, 4,720 International Units; vitamin B_1, 180 International Units; vitamin D, 540

A. O. A. C. chick units; vitamin G, 1,250 Cornell chick units. Smaller quantities of all except vitamin B_1—the requirement for this is low anyway—would usually be adequate for egg production if the eggs are not to be used for hatching, but it is advisable to feed at the higher vitamin level in either case.

The market quality as well as the quantity of eggs is affected by diet. It is reported that certain feeding stuffs give undesirable flavors to eggs if fed in excessive quantities. Eliminating green feeds and yellow corn from the diet produces eggs with light-colored yolks, and dark orange-red yolks may be produced by feeding ground pimiento pepper or chili pepper. Cottonseed meal tends to have an undesirable effect on the color of both yolk and white. A deficiency of vitamin D, calcium, or manganese results in poor shells. Too much bran and salt in the diet produces loose droppings that soil the eggs.

There is little evidence concerning the effect of diet on the fertility of males. The hatchability of eggs, however, is adversely affected by a deficiency of vitamin D, as in winter or under confinement. Feeding greenstuffs may improve hatchability by providing vitamin A, vitamin G, and other factors. Diet affects the percentage of protein in both the yolks and the whites, but apparently not the composition of the protein. It affects both the percentage and the composition of the fat. The content of minerals (calcium, phosphorus, manganese, iron, copper, iodine, fluorine) in eggs and developing embryos may be affected by diet and, in some cases, by irradiation with ultraviolet light. Second-week embryonic mortality is greater when the diet contains plant-protein than when it contains animal-protein supplements. An excess of vitamin D decreases hatchability. Too little manganese or calcium, or too much calcium in relation to phosphorus, affects hatchability adversely. Selenium has a toxic effect on embryonic development and hatchability. Sunshine has a favorable effect, apparently supplying some factor besides vitamin D.

For growth, chickens make more economical gains per pound of feed if they are fed at least 30 percent under the full-feeding level. However, they reach the heaviest weight and gain in the shortest time on full feed. In practice, then, they are fed all they can be induced to eat, so that egg or meat production may be pushed to the limit.

For growth of the young birds, special attention must be given to the amount and quality of protein, and to the quantities of minerals and vitamins, in the diet. If these are adequately supplied, the ration is not likely to be deficient in carbohydrates or fats. Particular care must be taken in the first few weeks after hatching, since this is the most critical period in the life of the chicken.

The best level of protein feeding for growth is probably at 20 to 21 percent of the ration. It is good practice to feed at this level to the age of about 12 weeks and then gradually decrease the protein content to 16 to 17 percent. Growing turkeys may be fed a ration containing 25 percent of protein to 12 weeks of age, gradually decreasing it to 17 percent at 24 weeks, then to 14 to 15 at marketing age, and finally to 13 to 14 for breeding stock over 30 weeks old; but the amount should be again increased to 16 to 17 percent before and during the breeding season.

A satisfactory level of phosphorus intake for the growing chicken is 0.7 percent of the ration, in combination with 1.12 percent of calcium. Manganese must often be added to the diet, as already indicated for egg production.

The minimum vitamin A level for growth is 780 International Units per pound of feed, and a satisfactory level is 1,450 International Units per pound. Much more than this may be fed without harm. Turkeys apparently require two to two and one-half times as much vitamin A as chickens. The most favorable vitamin B_1 level for growing chickens is about 180 International Units per pound of feed, and turkeys seem to have about the same requirement. A satisfactory vitamin D level for chickens is about 180 A. O. A. C. chick units per pound of feed; young turkeys probably require twice as much. Apparently young growing chickens and turkeys have the same riboflavin requirement—about 1,670 Cornell chick units per pound of feed. Other vitamins or factors are required but the quantities are not known.

Roasters, capons, and fowls may be fattened for market on diets containing considerably less protein (a level of about 14 to 15 percent) than is required for growth. The quantities of vitamins may also be reduced by half. Finishing diets may advantageously contain more fat, however—6 to 10 percent—some of which may be supplied by adding vegetable oil.

PRACTICAL FEEDING OF POULTRY

Two general rules in poultry feeding are that the feed should be palatable so that a large amount may be consumed, and that it should not be too finely ground.

The chief sources of energy are the cereal grains and the grain sorghums. In general the cereal grains are practically interchangeable except that corn is a better source of vitamin A than the others.

As protein supplements, feeds may be rated in the following order: (1) Dried skim milk, dried buttermilk, and fish meal (best grades); (2) meat scrap, poorer grades of fish meal, hempseed meal, soybean meal; (2 or 3) peanut meal; (3) cottonseed meal; (4) linseed meal, corn-gluten meal, ground soybeans. It is good practice to use animal products for 20 to 40 percent of the protein supply.

Sources of minerals are, for calcium, high-calcium limestone (preferably 39-percent calcium) or oystershells; for sodium and chlorine, common salt; for manganese, anhydrous manganous sulfate or manganous sulfate tetrahydrate; and ground bonemeal for phosphorus, when the diet contains little or no animal-protein supplements.

Sources of vitamin A are cod-liver oil, other fish-liver oils, cod-liver oil concentrates, sardine oil. Loss of vitamin A in fish-liver oils added to feed mixtures is fairly rapid so that mixtures should be made at short intervals. Alfalfa-leaf meal and fresh green grass are excellent sources of carotene, and other important sources are corn-gluten meal made from yellow corn, garden peas, yellow corn, field peas, wheat-germ meal, and cowpeas.

There is little likelihood that any typical poultry diet will be deficient in vitamin B_1. Sources of vitamin D, which should always be added to the diet of laying stock kept in confinement, are cod-liver oil, sardine oil, and other suitable fish oils. The best practical sources of vitamin

G are alfalfa-leaf meal, dried skim milk, dried buttermilk, dried whey; other rich sources are liver, glandular tissues, and yeast. Vitamin K is found in various materials, including hempseed meal, tomatoes, kale, and dried alfalfa. An "anti-gizzard-erosion factor" has been found in wheat bran, alfalfa products, kale, wheat middlings, oats, and certain pork products. A "chick antidermatosis factor" is present in grains, peanut meal, dried whey, dried buttermilk, alfalfa meal, and other feeding materials.

Grit is not absolutely necessary for chickens, but it should preferably be supplied. A constant supply of fresh clean water should be available at all times. Tonics, conditioners, "egg-makers," and so-called complete mineral mixtures are a waste of money.

Dietary deficiencies lead to numerous ills, some of which are difficult to pin down to a definite factor under practical conditions. Feather-picking and cannibalism are perhaps partly due to dietary deficiencies not yet understood; they are less likely to occur if the diet contains barley or oats. Egg eating is stimulated by a deficiency of calcium or vitamin D. Nutritional roup (not the same disease as contagious catarrhal roup) is caused by a deficiency of vitamin A. Rickets follows a deficiency of vitamin D, calcium, or phosphorus, or a marked unbalance of calcium and phosphorus. A deficiency of vitamin G retards growth, decreases the hatchability of eggs, and produces "curled toe" paralysis in growing chicks. Lack of the anti-gizzard-erosion factor results in a condition of the gizzard that can only be diagnosed by dissecting the bird. Lack of the chick antidermatosis factor results in sores and incrustations around eyes, mouth, and toes. A deficiency of manganese produces hock disease or slipped tendon.

Nearly every poultryman has his own system of feeding, but in general they are of four types: (1) All-mash, (2) mash-grain, (3) pellet, (4) grain-milk. The important point is not the system but supplying all the necessary nutrients in adequate quantities and economically.

In the all-mash system, all or most of the feedstuffs are ground, mixed together, and fed dry or as a wet mash. This system is probably the best for the inexperienced poultryman. It is also best for all chickens up to the age of 4–6 weeks. It enables the producer to control the color of the egg yolks and to keep the color uniform; and apparently it results in more uniform hatchability.

The mash-grain system, in which both mash and grain are fed, is more flexible than the all-mash system, but it is best used by a skilled poultryman.

The pellet system simply involves the use of an all-mash diet prepared in the form of pellets. The chief advantage claimed for the pellets is that they prevent the birds from discarding certain ingredients in the ration.

In the grain-milk system, the birds are usually given nothing but grain and all the milk or buttermilk they will drink. No water is supplied. This system is not recommended except where there is plenty of good range and where milk is practically a waste product.

Formulas for all-mash starting and growing diets, all-mash diets for laying and breeding stock, starting and growing mashes with which grain is to be fed, laying mashes to be fed with grain, and feed mixtures for turkeys are given in the article on Practical Feeding of Poultry and cannot be repeated in this brief summary. Substitutions can be made for some of the ingredients in these formulas where it is economical to do so—an important point, since the cost of feed is 50 to 60 percent of the cost of producing poultry meat and eggs.

In any formula, only the best feedstuffs should be used. Abrupt changes in the diet are to be avoided, especially for laying stock. Only a little more feed than the birds will eat should be supplied each day. Sufficient hopper space should be provided to prevent crowding. Grain should not be fed in the litter—a common practice—but in the hopper. Houses should be well lighted to insure good feed consumption, and in winter artificial lighting may be used to lengthen the feeding day to about 14 hours.

NUTRITIONAL REQUIREMENTS OF DOGS

There is a difference of opinion among veterinarians and breeders concerning the constitution of a proper diet for the dog. Most of them agree that meat is the basis of all successful diets. Some say the dog cannot digest vegetable foods or starchy foods of any kinds. Others would allow a limited amount of carbohydrate. On the other hand, racing greyhounds in England are fed relatively large amounts of cooked vegetables with excellent results, and in nutrition laboratories dogs have been satisfactorily fed on diets without any meat.

The digestive organs of the dog are undoubtedly adapted to use concentrated and quickly digested foods such as meat. In animals that live on plant foods, the large intestine makes up a considerable proportion of the whole digestive tract. In dogs the large intestine is a very small part of the digestive tract and is not adapted for handling foods which leave a bulky residue after digestion. It has been proved that dogs can digest starch used in amounts sufficient to meet all their energy requirements, but it seems that they cannot very well break down the walls of the cells that contain the starch in plants. The starch should first be liberated by some such means as cooking or grinding. There is a good deal of individual difference, however, in the ability of dogs to handle plant fiber.

With a high percentage of foods rich in starch, it is more difficult to balance the diet with respect to other factors. For example, a large proportion of cereal interferes with the proper use of calcium in bone building. That can be corrected, however, by using sufficient fat probably not less than 11 percent in a high-cereal diet. The advantage of carbohydrates is that they are a cheap source of energy; and some carbohydrate is necessary if the body is to utilize fat in the diet. Vegetables, of course, are valuable as sources of necessary minerals and vitamins.

The proteins in animal products are of greater biological value than those in vegetable products because in general they are more complete in the amino acids needed by the body for building and replacement of tissues. Milk and eggs rank first in this respect; then liver and kidney; then muscle meat. Animal proteins can be used to round out the amino acids in vegetable proteins. It is apparently possible to use cereals exclusively as a source of protein, but this requires considerable care and knowledge. When vegetable proteins are used too exclusively, moreover, the diet is likely to be deficient in the B vitamins.

As for the proportion of protein in the diet—young dogs require considerably more per pound of body weight than mature dogs. Pregnant and lactating bitches require more also. It has been estimated that the most favorable proportion of protein for all dogs lies between 25 and 50 percent of the total dry weight of the ration. Another suggestion for an average diet includes 22 percent of protein, 5 of fat, 70 of carbohydrate, 0.5 of fiber, and 2.5 percent of minerals.

Small mature dogs require more energy per pound of weight than large mature dogs, and puppies require two or three times as much per pound as mature dogs. The energy requirement goes up with the activity of the animal. As a sample: A 44-pound dog may require 1,265 calories a day for maintenance alone. If he is moderately active, he will require about a third more than this; if he is very active, about two-thirds more. It is generally believed that a dog's appetite is not a safe guide to his needs, but one exprimeter reports that dogs will voluntarily adjust their food to their energy needs if all dietary essentials are offered in sufficient quantities and there are no pronounced mental influences operating.

Eleven minerals are considered to be essential in the dog's diet, and minimum requirements for each of them have been suggested. Calcium and phosphorus are the only ones that are likely to need special attention, especially during the growth period. A ration consisting of a large proportion of muscle meat alone or muscle meat and cereal is apt to be deficient in calcium, but the deficiency can be corrected with milk, bonemeal, ground bone, or calcium phosphate.

Like other animals, dogs have characteristic nutritional diseases when vitamins are deficient. Quantitative requirements have been estimated for vitamins A, B_1, D, and G, and nicotinic acid. It is believed that the dog normally makes vitamin C in its own body.

FEEDING DOGS

Animal products should ordinarily make up about half the ration of a mature dog (except when pregnant or lactating), vegetables about a fourth, and cereal products about a fourth.

Meats may be fed raw or cooked (but never fried), and glandular organs as well as muscle tissue should be used at least occasionally. Beef is preferred by most dog owners, but mutton, lamb, and horsemeat (if available) are also used. Pork is not usually relished by dogs, and poultry should not be fed because of the danger from easily splintered bones. Canned fish, or cooked fish with all bones removed, is a good protein feed. So are milk and eggs. Puppies may start on a teaspoonful of ground or minced meat when about 3 weeks of age, the amount being increased to 1 or 2 tablespoonfuls at weaning time (6 weeks) for medium-sized breeds.

Vegetables supply bulk and furnish vitamins and minerals. Carrots, tomatoes, spinach, onions, and beets are quite extensively used; cabbage, turnips, string beans, and certain other green vegetables less commonly; and potatoes, fresh corn, shelled beans, and peas are considered undesirable by many owners. Some dogs will avoid vegetables unless they are thoroughly mixed with other foods.

Cereal grains commonly used for dogs are corn, as corn bread; rice, boiled—brown or unpolished rice is preferable; oats, as cooked oatmeal; wheat, as bread or cereal; and barley, cooked (not very palatable). Dog biscuits, dry, moistened, or mixed with other foods, may be used as the cereal part of the ration. Usually these contain various other products—for example, ground bone, dried milk, legume meal, cod-liver oil, meat or meat byproducts, fish meal, molasses, yeast, salt. Dog meals contain much the same materials as dog biscuits. The typical composition of many of these products is two-thirds cereal products and the other third meat, dry skim milk, or other protein supplements.

Bones are a good source of calcium and phosphorus, and they are valuable for teething puppies, but they have disadvantages when fed to mature dogs to any great extent. Easily splintered and sharp bones or those that will lodge in the mouth or throat must never be used.

Canned dog foods generally consist of cooked meat or meat byproducts, fish or fish meal, cereals, vegetables, ground bone and other mineral matter, and various accessory substances such as yeast, cod-liver oil, and charcoal. Usually they contain 65 to 75 percent of water. They are convenient and widely used, but they may be uneconomical in comparison with home-prepared feeds, and it is well to do some experimenting, in any given case, to see whether they give the dog adequate nourishment. The label usually includes a statement of ingredients, but this cannot always be interpreted by the average dog owner.

Water, in clean vessels, should be available to dogs in most instances. Some salt should be mixed with the feed.

Pregnant bitches should have gradually increasing amounts of feed as pregnancy advances, and animal products may then make up 65 to 75 percent of the ration. Other special feeding practices should be followed at this time, as well as immediately after whelping. During lactation, the ration must be ample to cover the requirements for milk; in many cases, twice as much feed must be used as for a nonpregnant, nonlactating bitch.

Cows' milk is the best food for puppies preparatory to weaning. It may be started at about 3 weeks of age. Puppies should also become accustomed to other foods at an early age. Immediately after weaning they will have to be fed five or six times a day, gradually tapering off to two meals a day at 1 year of age. Growing puppies should have proportionately more animal products than mature dogs. It may be advisable to include a small amount of cod-liver oil in the ration, particularly during winter months.

The quantity of feed required by a dog depends on several factors, chiefly age, size, and amount of exercise. The young, growing dog needs considerably more feed per pound of body weight than the mature animal. Approximate daily quantities of feed (moisture included) for mature dogs of different weights getting moderate exercise are:

Body weight, pounds	Total feed, pounds	Body weight, pounds	Total feed, pounds
1	⅛	75	3¼
10	¾	100	4
25	1½	150	5¼
50	2½	225	7

These allowances can probably be reduced 25 to 35 percent for very inactive dogs and increased 25 percent or more for dogs that are very active.

Some other practical points about feeding:

A dog should be fed as well as other farm animals and not used as an extra garbage pail.

Overfeeding is more common than underfeeding. Both should be avoided. Most dogs will overeat if given the opportunity.

Puppies should usually be kept a trifle hungry by feeding a little at a time, but often. They should be kept growing steadily and uniformly.

Uniform body weight and a lean, thrifty condition are good guides in the feeding of the mature dog.

The crude-fiber content of the ration should be kept low—usually less than 2 percent.

It is good practice to feed twice a day—one meal heavy, the other light. Feeding should be at regular intervals, and not immediately before or after exercise.

If a dog that is adequately fed loses weight, intestinal parasites may be suspected.

In general, sick and convalescent dogs need easily digested, readily assimilable feed.

NUTRITION OF FUR ANIMALS

Foxes generally mate early in February. The pups are born in late March or early April and the animals are usually pelted the following November or December at about the age of 9 months. Animal products form the basis of the ration of foxes, which in the wild are carnivorous but eat some fruits and other plant products. Horse meat, including internal organs, often ground and frozen in slabs, is used by many ranchers. Beef meal (desiccated beef) is perhaps the most generally satisfactory substitute for raw meat. The foxes are fed differently in the summer-fall and the winter-spring seasons. With lower prices for silver fox skins and increasing competition, there is a strong motive for research that will lead to more economical feeding practices. Some nutritional research has been done by four States (Oregon, Michigan, Wisconsin, New York) and by the United States Fur Animal Experiment Station at Saratoga Springs, N. Y.

The rations given below are recommended as a result of considerable experimental work at this station, the principal object being to find satisfactory cheaper substitutes for fresh meat.

A recommended ration for mature animals during summer and fall consists (in percentage) of beef meal, 4.8; soybean meal (hydraulic pressure), 4.8; liver meal, 2.4; ground fresh carrots and tomatoes, 5; ground green bone, 5; dry mixture, 25; water, 53. The dry mixture consists (in percentage) of bread meal, 30; oatmeal, 30; alfalfa-leaf meal, 10; wheat-germ meal, 10; fish meal (vacuum-dried), 20. Each animal is given a restricted feeding of about 0.8 pound of this ration daily, increasing to 0.9 pound in cooler weather.

During the reproductive season (winter-spring) a recommended ration for breeding animals consists (in percentage) of raw meat (muscle 7 parts, glandular 3 parts), 40; ground green bone, 5; ground fresh vegetables, 10; cod-liver oil (fortified), 0.3; dry mixture, 25; water, 19.7. The dry mixture consists (in percentage) of bread meal (whole wheat), 16; oatmeal, 16; wheat-germ meal, 16; fish meal, 16; alfalfa-leaf meal, 8; dried skim milk, 8; soybean meal, 8; linseed meal (old process), 4; wheat bran, 4; brewers' yeast (inactive), 4. The animals should be fed what they will readily clean up in a short period, and the female should receive an increased amount beginning about the fourth day after whelping. Males may be taken off this ration and put on the summer-fall ration at the end of the breeding season.

Pups are fed with the mother during the suckling period, receiving the same ration. If weaned at 7 to 8 weeks of age, they should continue to get this ration until the age of 2½ to 3 months, when the raw meat can be replaced with a mixture of 4 parts of beef meal to 1 part of liver meal, this mixture making up 12 percent of the ration. Additional water must of course be used. About September 1 the pups can be put on the summer-fall ration of mature animals.

According to the average chemical analyses of various ingredients, summer rations used at the fur animal experiment station contain, on a dry-matter basis, approximately 42 percent of protein (about two-thirds from animal and fish sources), 6.4 of fat, 37 of carbohydrate, and 9.7 of minerals. No published data of digestion trials on foxes are available to show how much of the nutrients are utilized.

Analyses have been made of the livers of foxes for vitamin A content. These show that the livers of wild foxes contain on the average about twice as much fat and about 100 to 200 times as much vitamin A as those of foxes raised in captivity. Gallstones (urinary calculi) are considered by some to be due to lack of vitamin A. Apparently there is no correlation between the amount of vitamin A in the liver at the lower levels found in the silver fox and quality of pelt. Green of Minnesota attributes the disease known as chastek paralysis in foxes to a deficiency of vitamin B_1, and believes it is caused by substituting fish in the ration for other foods that contain vitamin B_1.

Minks apparently need more raw meat than foxes; it should make up about 50 percent of the ration in summer and fall and about 70 percent during the breeding and lactation periods. The meat may consist of muscle meat 2 parts, viscera 1 part, from horse, cow, or sheep. Fresh chicken heads, rabbit heads, or rabbit carcasses may be used; whole fresh ground fish or canned fish may be substituted for one-third of the raw meat. On the basis of limited experimental work at the fur animal experiment station, a satisfactory ration during the breeding season may consist (in percentage) of fresh meat, 70; dry mixture (as given for foxes during the reproductive season), 10 to 15; ground green bone, 5; ground fresh vegetables, 5; salt, 0.5; cod-liver oil (fortified), 0.3; water or fresh milk, 4.2 to 9.2. During summer and fall the ration may consist (in percentage) of fresh meat, 50; dry mixture (as given for the summer-fall ration of foxes), 25; ground green bone, 5; ground fresh vegetables, 5; salt, 0.5; cod-liver oil, 0.3; water or fresh milk, 14.2. The animals should be fed 4 to 5 ounces of the ration once a day (not enough to make them fat), except that nursing mothers should be fed twice a day.

As in the case of foxes, lack of vitamin A has been suggested as the cause of gallstones, which have brought considerable losses in some colonies of mink. A study of the vitamin A content of livers showed that wild mink averaged about 16 times as much as those raised in captivity. Digestion trials have been run on mink at Cornell University. In general, these show that mink are not able to digest carbohydrates nearly so well as proteins and fats, and that starch in grains is made more digestible by cooking.

Rabbits are raised in this country primarily for meat, but furs are sold to the hatters' trade, with a small percentage going to the fur trade. As a result of work at the United States Rabbit Experiment Station, Fontana, Calif., the following recommendations for feeding are made: Does suckling young should be fed from a self-feeder with several compartments, which should contain at least two whole grains (oats, wheat, barley, sorghum) and a protein supplement (soybean meal, peanut meal, or linseed meal) in the form of pea-sized cakes or pellets three-sixteenths of an inch in diameter and one-eighth of an inch long; or they may be hand-fed with a mixture of 2 parts whole grains to 1 part protein supplement. Clean, bright, leafy legume hay (alfalfa, clover, lespedeza, or pea-vine) cut into 3- to 4-inch lengths should be available in a manger at all times. A small quantity of succulent green feed or roots should be supplied daily. White block salt and fresh water should always be available.

After the litter is weaned the doe should be fed once daily as much small grain (2 parts) and protein supplement (1 part) as she will clean up in 20 to 30 minutes, plus the other feeds given above. Herd bucks and young does and bucks may be fed the same ration.

FEEDING REQUIREMENTS OF GALLINACEOUS UPLAND GAME BIRDS

During the past 50 years or more in the United States, many game birds have been forced almost to extinction. Today there is an awakened public interest in preserving them, and a good many people, among whom are farmers and 4 H club members, now make a business of raising game birds in captivity. Those most commonly bred, according to a recent survey, are the ring-necked or Chinese pheasant, bobwhite quail, California and valley quail, and chukar partridge. Other important upland species on which some work has been done in captivity include the ruffed grouse, sharp-tailed grouse, prairie chicken, sage hen, mountain quail, Gambel's quail, scaled quail, Hungarian partridge, and wild turkey. More and more scientific attention is being given to the feeding and management of these birds.

Investigations by the Bureau of Biological Survey give a good picture of the food habits of game birds in the wild. Different species have somewhat different habits, of course, but in general seven kinds of food are consumed—weed seeds, in large quantities; insects, especially grasshoppers and their relatives; seeds of cultivated plants; mast, or tree seeds; browse, or leaves of plants, including woodland trees; berries and small fruit; and minerals, including pebbles. The quantities and kinds of different foods in bird crops from various areas and at different seasons have been carefully recorded.

Farmers can do much to build up the game-bird population, and help to prevent erosion at the same time, by providing shelters of natural vegetation in waste areas. It is highly advisable to provide food during the winter, since a food shortage lasting a week will starve many birds, and one lasting 2 weeks may kill off most of the game-bird population. Food patches may be planted to grain, especially corn; rough shelters or feeding stations can be set up near good protective cover; and in an emergency, feed can be scattered wherever the birds will find it.

In the wild state, birds are able to get a properly balanced diet for themselves. In captivity a balanced diet must be provided with even greater care than would be used in feeding chickens. Cereal grains and protein concentrates can both be used though only a little experimental work has been done to show how various grains and concentrates meet the requirements of game birds. As with chickens, the ration must furnish adequate quantities of vitamins A, B_1, D, and G, as well as of common salt, calcium, phosphorus, manganese, possibly some other minerals, grit, and water. There has been some experimental work on the requirements for most of the important nutritive elements, but as yet very little information is available.

Two notable changes have been made in the management of game birds in captivity. The tendency now is to keep them on wire cloth in runs rather than on the ground, to prevent the spread of disease; and the chicks are no longer fed on a custard-clabber diet, which is difficult to prepare and at the same time a source of parasitic infestation, but on feeds like those used for domestic fowl.

PASTURE AND RANGE IN LIVESTOCK FEEDING

Some 60 percent of the total land area of the United States is grazed at least part of the year as pasture and range. Pastures probably provide about one-third of the nutrients used by dairy cattle at perhaps one-seventh of the total feed cost, as well as half the feed of beef cattle at one-third the total feed cost, and half the feed of sheep in pasture regions; while livestock on the range get much more than half their feed from range plants. In one study in New York the cost of milk production on pasture was 9.7 cents per cow per day and on winter feed 38 cents per cow per day. There is no more land to be taken up free for pasture. The problem now is to save and improve what we have. Research shows that better grasses can be provided and the nutritive value of pasture plants can be increased.

Pastures are classed as permanent, temporary, and supplemental. Longer grazing can usually be provided by a combination of all three than by permanent pasture alone. On the range, somewhat the same objective is accomplished by moving livestock to different ranges kept for different seasons.

Grazing is usually seasonal except in certain areas, where it may be yearlong. Premature grazing and overgrazing are both injurious, partly because they use up the sugars from which plants must get the energy for growth. In the early spring, plants get the energy for growth from sugars stored in the roots; later on they get it from sugars manufactured from day to day. On the other hand, under some conditions undergrazing permits the grass to mature too soon and become less valuable as feed. Much would be saved if grass could be clipped and ensiled under these conditions.

Pasturage is of great importance as a source of proteins, minerals, and vitamins. Immature plants are more tender, more completely digestible, more palatable, and richer in protein, calcium, phosphorus, and vitamins than the same plants later in the season. Low rainfall and high temperatures adversely affect the nutritive value of grasses except the species adapted to these conditions, as in the West and South.

In managing pastures, it is desirable to have a mixture of grasses and legumes, and of several grasses rather than one grass. Legumes in themselves add to the protein in the feed, and their presence also increases the growth and the protein content of the grasses. The grasses that are most palatable to animals should be used wherever possible. Fertilizers should be used not only to correct soil deficiencies but to suit the particular needs of different plants; grasses, for example, respond to nitrogen better than legumes, and legumes are more responsive to phosphorus and potash. It should be remembered that fertilizing pastures is a long-time investment, which helps to liquidate the high initial cost. The time and intensity of grazing depend largely on the kinds of plants used.

Supplemental feeding of animals on pasture is frequently necessary or advisable, especially after the first flush period when the forage has its maximum nitritive value, or, in the West, on winter range.

Range problems are different from pasture problems, partly because it is not possible to exercise the same control through planting and the use of fertilizers. The range territory produces 75 percent of the total United States production of wool and mohair, 55 percent in live weight of the sheep and lambs, and nearly 33 percent of the cattle and calves. The area shows a bewildering complex of Federal, State, county, and individual ownership, which complicates the problem of use and management. Herds are often driven 50 to 150 miles between summer and winter ranges, and sometimes as much as 300 miles.

Little reseeding has been attempted anywhere on the range. Out of a total of at least 10,000 species of plants growing on the range, probably only 1,000 are of major significance. In general, the plants fall into 10 broad types, according to differences in soil, temperature, and rainfall. The tall-grass type (including slender wheatgrass, bluestem, porcupine grass) has the greatest carrying capacity--2.4 acres per head of cattle or 5 sheep; the salt-desert shrub type (including black sagebrush, shadscale, winterfat), the lowest capacity--17.8 acres per head of cattle or 5 sheep. The older natural balance of plants in the range area has been disturbed by man's use, and the principal perennial grasses, which were the most nutritious and palatable, have given way in most places to less useful species.

Many range plants—for example, some of the wheatgrasses, saltbushes, and native clovers—compare favorably with alfalfa in chemical composition, and some have an even higher proportion of minerals or protein. There are many variations due to environment, however. In general, the plants at the higher altitudes have more crude protein and less fiber. It has been found that the sulfur, protein, and fat content of the plants vary directly with their phosphorus content. Research in the composition of range forage plants is comparatively new.

Good management is vital on the range if its productivity is to be maintained. The plants are fitted to grow well with little water—some range grasses require only 400 pounds of water to produce 1 pound of dry matter, whereas alfalfa may require 800 pounds—but they sometimes need twice as much water when the soil is depleted by erosion. Because of wide fluctuations in production from year to year, stocking should normally be 20 percent below the capacity in average years. The returns in increased calf crops, greater weight, and reduced losses in drought years from conservative stocking as compared with overgrazing have been proved again and again.

In the South, livestock production might be considerably increased through better grazing methods in the forest ranges.

Research on the effects of soil and fertilizers on pasture plants is only at its beginning, but some interesting and promising results have been obtained. Some examples: It is becoming clear that different plants have the ability to select and utilize different nutrients from the soil. Nitrogen applied to Kentucky bluegrass increased the crude protein content 12.34 percent in one experiment; sulfate of ammonia increased it 4.44 times in another experiment. Adding phosphorus increased the phosphorus content of Kentucky bluegrass 25.64 percent and the calcium content 16.67 percent in one experiment. (The effect of adding phosphates varies with different soils, however.) On certain soils in the West, applications of sulfur are necessary to satisfactory yields of alfalfa, and this increases the nitrogen as well as the sulfur content of the plants. Instances have been reported in which light applications of boron have benefited alfalfa.

Such studies point toward the possibility of better control of both plant and animal nutrition in the future through soil management.

THE NUTRITIVE VALUE OF HARVESTED FORAGES

Hay is the most important harvested forage and can be made at comparatively small expense. Crops unsuitable for hay may be made into silage, and almost any forage crop can be ensiled in weather unsuitable for haymaking. Between 1928 and 1937, the hay crop had an annual value greater than that of cotton or wheat or any crop except corn.

Any crop loses nutritive value after harvesting. The objective is to harvest and store it in such a way as to maintain the greatest nutritive value possible and reduce losses to a minimum. Three points of importance are:

(1) Stage of growth. Plants have the highest nutritive value when they are young (protein in alfalfa at the prebloom stage is 21.98 percent; at the seed stage, 14.06; minerals are 11.24 and 7.33 percent, respectively). But the yield from young plants is low and the labor cost of harvesting them frequently is high. Therefore forage plants are usually harvested at an intermediate stage—grasses, clover, and alfalfa, between early bloom and full bloom (or before bloom for a very high quality hay); cereal grains for hay, in the soft dough stage; soybeans, when beans are about half grown; cowpeas, when first pods are mature. Maximum leafiness is also highly important, as the leaves contain much more carotene, protein, and minerals, and much less crude fiber, than the stems. Early-cut hays have a high percentage of leaves.

(2) Species of plant. Legumes are characterized by a high content of protein and minerals. Alfalfa is the most valuable and most popular. Red clover, soybeans, cowpeas, alsike clover, and lespedeza all make good legume hays. Mammoth red clover, crimson clover, sweetclover, and peanut vines are less important. Timothy is the most important of the grasses. Prairie grass (in the West), small grains, and sorgos are popular in different regions. Certain sedges and rushes, Johnson grass, red top, bromegrass, quackgrass, Bermuda grass, orchard grass, Kentucky bluegrass, crested wheatgrass, and crabgrass make acceptable hay if properly handled. Mixtures of legumes and grasses are commonly used and are very desirable.

(3) Quick, thorough drying. In 30 hours, even in good hay weather, cut alfalfa in the field may lose 60 to 65 percent of its carotene. Even artificial drying usually fails to save all of the carotene in the fresh green crop. Much of the loss can be prevented by complete exclusion of air or by destroying an enzyme responsible for the destruction of the carotene. Under practical conditions, however, the only way to reduce the loss to a minimum is by rapid drying. Carotene is closely associated with the green color of the plant. Partly cured hay that has been rained on loses green color rapidly.

If possible, hay should be cut in the morning after the dew is off and stored the same day. At any rate, it should not be allowed to lie in the swath overnight if it is dry enough to finish curing in the windrow. Legumes should be raked into the windrow before the leaves are dry enough to shatter. The side-delivery rake gives a more loosely packed windrow than the dump rake. The hay may be cocked if there is a prospect of much rainy weather before storing. When stored, it should be dry enough so it will undergo only a normal sweat. Stored hay with more moisture than this will lose color markedly; if it becomes brown, all the carotene is lost; if it becomes black, there is an additional heavy loss of other nutrients. Tight packing and poor ventilation as well as high moisture content help to bring about loss of color in hay. With equal moisture content chopped hay becomes hotter in the mow, dries less rapidly, and loses more color than unchopped hay.

The nutrients in hay are better preserved by artificial drying than by any other method, and the losses due to weather and leaf shattering are reduced to a minimum. The cost of buying and operating the drying equipment, however, is more than the average individual farmer can afford. Hay well wilted in the field can hardly be artificially dried for less than $5 per ton of dry material, and the cost is likely to run much higher. The method is used mainly by commercial concerns making alfalfa meal, alfalfa-leaf meal, and alfalfa-stem meal. The first two are used principally in feeds for poultry, hogs, and dairy cattle, and the last as a carrier for molasses feeds for horses and mules. Alfalfa meal is made by grinding whole alfalfa hay. The leaf portion is sifted out after grinding to make leaf meal, leaving the stem portion for the byproduct, stem meal.

Silage is moist feed preserved in the absence of air. It is made mostly out of corn and sorgos, but small grains, oats, and peas, and sunflowers are used to some extent; and in recent years grasses and legumes have been ensiled to an increasing extent. "Succulent" feeds like silage are not necessary for livestock, as they were once thought to be, but silage is often economical in the feeding program. It is better adapted for ruminants, especially cattle, than for other livestock.

When crops are put into the silo, they continue to breathe, use up the oxygen, replace it with carbon dioxide. The temperature rises and bacteria multiply rapidly (in corn silage they reach a billion per cubic centimeter of juice in a few days), consuming mostly carbohydrates and producing lactic acid. With this increase in the acidity.the lactic acid bacteria diminish in numbers and acetic acid bacteria, which thrive at higher acidities, replace them. In silage made of grasses and other crops low in carbohydrates and high in calcium, acidity does not increase to such an extent; therefore acids or molasses are sometimes added for these crops.

Two exploded theories about silage:

(1) High acidity is not necessary for the preservation of silage to prevent molding or rotting, as is commonly assumed. What is necessary is quick exhaustion of air, and its exclusion thereafter; hence a tight silo is essential. But high acidity does prevent undesirable fermentations that create offensive odors, and it prevents protein breakdown and lessens loss of dry matter. However, adding hydrochloric and sulfuric acids, as in some foreign methods, has distinct disadvantages; principally, it seriously impairs palatability, and it must be neutralized, usually with finely ground limestone, before feeding. Liquid phosphoric acid in the amounts generally used does not appear to impair the palatability. Molasses improves the odor and palatability of high-moisture silages made from grasses and legumes, but its value when used with other silages has perhaps been overemphasized.

(2) It is not necessary for silage to have a high content of water, as is commonly supposed. Low-moisture silage undergoes fermentation of a more desirable type, with lower losses of dry matter, better odor, and greater palatability. Crops with any moisture content from 70 percent down can be successfully ensiled if air can be properly exhausted and excluded. In practice, the crop should probably not be dried below a 50-percent moisture content.

Any kind of silo will do if it excludes air and surface or seepage water—tower, pit, trench, or even a piece of snow fence rolled into a circle and lined with paper. Corn for silage should be harvested when more than half but not all of the kernels have hardened—or earlier if a high content of carotene is desired. Grasses and legumes should be ensiled at the stage of maturity best for hay. All silages should be finely chopped.

LOSSES IN MAKING HAY AND SILAGE

Even with normal practice and under normal weather conditions the loss of dry matter in haymaking amounts to a tenth of the crop, or at least $75,000,000 a year. This is a conservative estimate, since the weather is often unfavorable in many sections. Losses as the result of rain may amount at times in certain localities to half the crop. Losses from dried plants leached by rain may be as high as 67 percent of the minerals, 35 of the carbohydrates, and 18 of the protein. As much as 82 percent of the carotene may be lost during the first 24 hours after hay is cut, and intermittent sunshine and rain while alfalfa is in the swath may bring about an almost total loss of carotene.

All this throws emphasis on the possibility of saving such losses through newer methods involving the use of artificial drying. An insignificant percentage of the crop is artificially dried at present, and the method is expensive, but its adaptability for certain sections of the country where conditions for field curing are not ideal deserves close study.

Artificial driers are of four types. Tray driers dry the hay in batches, and it is hand-shaken from one tray to another halfway through drying. In belt driers the hay is put on a belt at one end and emerges dry at the other without handling. In rotary driers, it is dried in a revolving drum. In pneumatic driers it is carried along in a drying current.

Artificial drying can be done in any weather. There is no loss from leaching and there need be little or no loss from shattering of leaves. The total loss of nutrients should not exceed 5 percent. It has been shown that artificially dried alfalfa may have 2 to 10 times as much carotene as normally field-cured alfalfa.

Another new method that may have promise for certain sections of the country where grass grows well and there is a lack of concentrated feeds is the artificial drying of young grass, before the nodes are formed. Such young grass is extremely rich in protein, fat, minerals, and vitamins. The protein content varies with the period between cuttings. If the grass is cut weekly the dried product may have a protein content of about 21 percent; if it is cut every 5 weeks, 14 percent. The carotene is retained almost entirely provided the grass is not wilted before drying.

Young grass may also be steamed in troughs to reduce the moisture content to less than 10 percent and then compressed with a hydraulic press into cakes until a ton of the grass would occupy a cubic space less than 3½ feet on each side. The original color of the grass is retained, and the cake has been found to contain as much as 23 percent of protein—two and one-half times as much as ordinary hay. A yield of 3½ tons of dried young grass to the acre is obtained when cuttings are made monthly, and it is claimed that young grass provides more protein per acre than almost any other crop. The experimental work with this method has been done in England, where conditions are unfavorable for haymaking but favorable for the growth of grass.

Dried young grass may also be ensiled as well as pressed into cakes.

The amount of corn silage produced per acre in the United States varies from 4 to 20 tons. As much as 40 tons of sunflower silage may be produced per acre. A ton of silage can be made from the amount of corn that would yield 5 to 5½ bushels of shelled grain. A hundred pounds of the dry matter in corn silage contains about 40 pounds of total digestible nutrients. These figures give some idea of the economic value of ensiling as a means of conserving feedstuffs.

Prevention of losses is important. With a consumption of 40,000,000 tons of silage a year, a loss of 5 to 15 percent amounts to a great deal.

Losses are perhaps smallest in silage made in a tower silo and highest in stack silage; in the latter, 30 percent of the dry matter is frequently lost on the top and sides. The loss of dry matter in good corn silage in a tower silo is about 10 percent.

Among the various methods of making silage, the more important include:

The A. I. V. patented method, originated in Finland. Twice-normal strength acid (hydrochloric and sulfuric) is added to the silage to increase the acidity of the green crop as quickly as possible and suppress bacterial fermentation and respiration.

The molasses process (mostly used with legumes, grasses, and cereals). About 3½ to 5 gallons of molasses per ton, the amount depending on the kind of crop, is added to the silage, supposedly to increase the acidity.

Whey method. Dry or concentrated whey, alone or inoculated with lactic acid bacteria, is added.

Defu solution. This is a modification of the A. I. V. method, using hydrochloric acid plus a little phosphoric acid.

Crema or Samarani process (developed in Italy). This consists in tightly compressing a partly wilted (low-moisture) crop in an airtight silo to hinder bacterial growth and prevent heating.

Among the conclusions that may be drawn from a considerable amount of experimental work with silage are these: Air is enemy No. 1. Undue losses may be prevented by the quick development of carbon dioxide, as when heavy pressure is used, or by the production of sufficient acid, as in the making of ordinary corn silage under American conditions. The use of silage made by the addition of mineral acids or chemical sterilizers has not yet been proved to be safe in long-time feeding procedures; and the desirability of these acids as compared with organic acids developed by natural processes is questionable. The use of lactic acid, which may be produced as a waste product on the farm, is worth further study. Much of the data on silage making is inconclusive, and there is room for cooperative, systematic study of many important aspects of the silage problem.

NUTRITIVE VALUE OF MISCELLANEOUS FEEDS

A great many miscellaneous feeds are available for farm animals in addition to pasture, the more important forage crops, and the more important grains. These miscellaneous feeds include various byproducts. It is important to remember that any change in the natural product results in a concentration or reduction in nutritive value and presents a new problem in balancing the ration.

Seeds and their byproducts are frequently used as sources of protein. Among the whole seeds used —aside from the more important grains, such as corn, oats, rye, and barley—are soybeans (40 percent protein), cottonseed (20 percent), flaxseed (25 percent), peanuts (25 percent). Nonleguminous seeds are low in calcium.

Meal and cake made from seeds from which the oil has been extracted contain a higher percentage of protein and minerals than the whole seeds. They are also high in total digestible nutrients. The most important are cottonseed meal and cake, corn-oil meal, soybean-oil meal and cake, peanut-oil meal. Coconut (copra) oil meal and cake are used in some localities. Sesame seed, sunflower seed, rapeseed, hempseed, rubber seed, and palm nuts are also used to make meal or cake, but these are of little importance in this country at present.

Mixtures of meal and hulls, such as cottonseed feed and oat mill feed, are lower in protein and total digestible nutrients and higher in fiber than the straight meal. Hulls and some other byproducts are of still lower grade, but they are important as roughage in some areas, as are legume straws and pea-cannery waste.

Milling byproducts of value for protein, total digestible nutrients, and sometimes minerals and vitamins include wheat bran, wheat middlings and shorts, wheat-germ meal, corn-germ meal, corn-gluten meal, corn-gluten feed, brewers' rice (broken kernels of rice), rice bran, rice polish. Low-grade products include rice hulls (flinty—not a desirable feed); grain screenings; grain screenings waste, refuse, and scourings.

Brewery and distillery byproducts include brewers' dried grains, distillers' dried grains, malt sprouts, dried yeast (high in vitamin G).

Cereal straws and hulls are high in fiber and low in nutrients, but some, such as oat straw and corn stover, are considered of value in maintenance rations.

Animal and fish byproducts are widely used as sources of protein and sometimes minerals and vitamins. Those that have not been subjected to high temperatures in processing are preferable. Packing-house byproducts include blood meal, digester tankage, meat-meal tankage, bonemeal (raw and steamed). Milk byproducts include dried skim milk, dried buttermilk, and dried whey. Fish byproducts include fish meal, fish-residue meal, crab meal, shrimp meal, whale meal.

Roots and tubers—including beets, sugar beets, cassava, carrots, chufas, Jerusalem-artichokes, mangel-wurzels, parsnips, potatoes, sweetpotatoes, rutabagas, turnips—are high in water content but have readily digestible energy nutrients. Yellow carrots and sweet-potatoes are good sources of carotene; beet and carrot tops are rich in vitamin G. Dried beet pulp, molasses beet pulp, beet molasses, and cane molasses are good sources of energy and are appetizing in feed mixtures.

Supplementary feeds sometimes used as sources of calcium include limestone flour and wood ashes. Raw and steamed bonemeal, bone ash, spent bone black, and dicalcium phosphate contain phosphorus as well as calcium. Sources of iodine (to be used carefully and only when necessary) include sodium iodide and potassium iodide.

Part 1

HUMAN NUTRITION

FROM TRADITION TO SCIENCE

by Louise Stanley[1]

WHEN all men got their food directly from nature, as hunters, fishers, or farmers, they could be more sure, in some ways, of getting a balanced diet than they can today. This article contrasts the old and the new relationship of men to the food supply, and shows how the modern science of nutrition is necessary to meet complex modern conditions.

NUTRITION has to do with the use living organisms make of food. All living things require food. Green plants take their food supply in simple inorganic forms from the soil and from the air and build it into more complex materials. They are able to use the energy of the sun directly in building the sugars and starches and cellulose, so important in their structure and life functions, from water and carbon dioxide. Excess energy is stored as sugar or starch or may be changed into the more compact form of potential energy—fat. This ability of the green plants to build simple inorganic material into complex, energy-containing organic compounds is of basic importance to animal life also, for animals must rely upon the energy originally stored by plant life.

Plants also absorb minerals along with the water from the soil—nitrates, phosphates, and sulfates—and from these and the carbohydrates build proteins in the many complex forms essential to the plant. These too are suitable in varying degrees for building the tissues of the animal or human body. Calcium, magnesium, iron, iodine, and various other minerals are built into plant tissues in forms available to animal life. Vitamins are a product of plant growth.

All our foods, therefore, are directly or indirectly derived from plants and have their roots in the soil. The soil, through its influence on food composition, has played an important part in determining the development and the survival of animals and men. First the soil, then plants, then animals—so has life developed. It is in the study of nutrition that the interrelation of the three is shown most clearly.

To appreciate the importance of nutrition to human life, one needs to look back to get the proper perspective. Man is the combined product of inheritance and environment. Food is the environmental factor that most directly controls his physical development; and it probably plays an important part in setting the pattern of nervous and emotional responses that make up the total personality.

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Marett (*745*)[2] makes a good case for the thesis that a natural selection of various food substances, based on economy, has played a very important part in guiding the evolutionary process. The minerals and vitamins in foods, through their effect on the composition of body tissues and fluids and on the development of the glands controlling internal secretions, profoundly influence the internal environment of the body cells and thereby affect growth, physical form, and emotional reactions.

Primitive man was restricted to the food supply immediately at hand. This supply was determined in both quality and quantity by the soil and climate. The kind of food available and its composition were important in determining survival and the differences in the physical development of men from different areas. Food supplies had geographic limitations. Some groups of men died out altogether, others changed form through generations as the result of natural diet restrictions. Thus through painful and costly experience, with much loss of life by the way, racial food habits and appetites were built up and came to be fair guides to the choice of food under simple conditions of living.

Nomadic tribes enlarged the areas from which they obtained food. The soils in these areas varied, and certain tribes probably selected certain areas that proved more conducive to survival than others. But still food supplies were limited. With the development of agriculture, food supplies were less accidental, but they still depended upon the soil and the weather. Within such limits, food habits were the result of racial experiences and were probably responsible for clear-cut racial physical differences. These deeply ingrained survival patterns are the basis for the so-called natural instincts sometimes referred to as guiding food choice.

As the result of experience, the relation between certain foods and certain physical conditions was known long before anyone knew the real explanation. Burned sponges were used in the thirteenth century to treat goiter. It was not until 1819 that the chemist Dumas discovered iodine in this ash. Cod-liver oil was used to treat rickets centuries before vitamin D was discovered. Florentine pharmacists of the middle ages were selling lemonade as a remedy for scurvy long before vitamin C and its significance were recognized.

Strangely enough, groups with restricted natural diets seemed to acquire a special taste for foods we now know were specially needed in these diets. Hrdlička reports that among the Indians of the Southwest, where meat is scarce, fat and marrow are much relished. Squirrels, prairie dogs, and fat field mice are considered delicacies. Among the vegetables, chili and tomatoes are emphasized.

The Mexicans, among whom milk is scarce, use an abundance of the vitamin A-rich pimiento. In Puerto Rico, annatto is used along with lard as a routine in cooking. This annatto has been shown to be a rich source of vitamin A, so likely to be lacking in the Puerto Rican diet.

New knowledge of nutrition gained during the last three decades explains such food habits and some folklore. But more important, it gives a rational basis for food selection that, applied through planned production, education in food choice, and more satisfactory distribution, can be used to increase the length and improve the quality of human life. Fewer natural foods and more processed and fabricated foods are used today. There is a far greater variety of foods available. Tastes have changed. As a result, racial habits and appetites can no longer be depended on to guide the choice of food.

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[2] Italic numbers in parentheses refer to Literature Cited, p. 1075.

Meanwhile, commercialization of food production and increased transportation of food from place to place and country to country have completely changed the problem of the food supply. Comparatively few families produce any of their own food except outside of the cities, very few indeed all the family's food. Rarely is all the food for an individual or a family drawn from so restricted an area that soil deficiencies affect the total food supply, with the possible exception of a deficiency of iodine. Iodine is added to the diet in areas where it is known to be lacking in the soil. But as food production has become more specialized and commercialized, economic factors have come to complicate food choice and in many cases limit the family food supply in ways that were not formerly true. Furthermore, economic competition in production and processing has a greater effect on food composition than the soil has.

Studies show that below certain income levels most diets are deficient. Calcium deficiency is just as serious in its effects when it is due to inability to purchase calcium-rich foods as when it is due to producing food on calcium-poor soils. Human nutrition is an economic and an educational as well as a scientific problem.

We now produce a great variety of foods of high quality. The pleasure associated with eating has become more refined. Flavor and keeping quality tend to be emphasized to the neglect of the nutritive values of foods. Processing, packing, and special services have added to food prices. The purchaser rarely knows which portion of his dollar goes for services and which for the food itself. There is little opportunity for obtaining food without these services.

To protect the consumer, the Government has established certain safeguards. As a protection for health, the Food and Drugs Act prohibits the use of certain substances in foods and requires that the presence of others be indicated on the label; as an economic safeguard it requires that foods conform to certain definitions. The Bureau of Animal Industry, through its inspection service, protects the meat supply of consumers. The Bureau of Dairy Industry, in conjunction with the Public Health Service, establishes standards to safeguard the milk supply.

But the final selection of food is an individual and family problem. The science of nutrition now offers a guide to this selection. It shows the importance of food to the well-being of the individual and the community. It tells how to advance this well-being and safeguard health. It offers certain standards in terms of groups of common foods to meet different economic needs as well as different preferences and habits. It is not a substitute for tradition and race experience; it supplements them and corrects them where they need correcting. Education is needed to make this science better known. Agriculture and industry must solve the problems of producing and distributing foods of high nutritive value.

tions to measure the extent and rate of oxidation of food in the body by measuring the amount of oxygen used and the rate at which the body uses it.

Almost all kinds of foods have some fuel value. The digested products of protein, carbohydrates (starches and sugars), and fats in food are oxidized in the body to produce heat and muscular activity. For a given weight, carbohydrates and proteins yield the same amount of heat or energy in the body, while fats yield more than twice as much. The percentages of protein, carbohydrates, and fats in different foods vary widely.

Aside from the food our bodies must oxidize in order that we may be physically active, a certain amount must continually be burned to keep the body warm and to furnish energy for breathing movements, the beating of the heart, and other physiological activities. The rate of energy expenditure by the body at rest is called the basal metabolism. Basal metabolism is measured in the morning before breakfast, when digestion and assimilation of food are not in progress. The measurements are made while the body lies in a state of complete rest and under comfortable conditions of temperature. The amount of oxygen used up under these circumstances varies with the body surface of the individual. After many years of careful and tedious study, it was found that the basal metabolism for each square foot of the body surface is almost the same for all normal well-nourished persons of the same age and sex.

A method was also found whereby the total body surface could be estimated from measurements of the height and weight of the body. With this knowledge, it becomes possible to determine whether the basal metabolism of any individual is normal or abnormal, and this is an early step in diagnosing certain diseases.

Ordinary mixed diets contain some materials, such as cellulose, that are not digestible. In addition, about 2 percent of the real food value of the diet escapes digestion and is lost in the excreta. Besides this a certain amount of the fuel value of the food is normally used up in the process of digestion itself; this has been called the cost of digestion.

Muscular activity increases the amount and rate at which food is oxidized by the body. Since this calls for more oxygen, we breathe more rapidly when we work than when we sleep or rest. In such exercises as swimming and rowing, the body uses food and oxygen from 8 to 14 times as fast as when it is at rest.

The fuel used as a source of energy for engines can in part be transformed into motion of a wheel or rod. This motion can be harnessed and made to do work. The percentage of the heat value of the fuel which an engine can transform into work is spoken of as its mechanical efficiency. The mechanical efficiency of the body is about 16 to 25 percent greater than that of steam locomotives and about the same as that of automobile engines.

A man or woman who follows an occupation requiring moderate activity needs about twice as many food calories as are necessary for his or her basal metabolism.

If the fuel or caloric value of the food eaten by a normal adult is more than is required to maintain the body and to provide for bodily activities, the individual is very likely to take on weight. If the caloric value of the food is regularly too small to meet these needs, the body weight drops. Whether a normal adult will grow fat or thin is not just a matter of whether he eats much or little, but whether he eats much or little in relation to his physical activities and possibly his glandular balance. One can become fat as a result of eating too much, exercising too little, or both.

Many men and women who follow no other guide than their natural appetites and who vary their activities widely do not change in body weight over a period of many years. In such cases appetite closely follows the need for food. Some men and women, however, remain overweight in spite of the fact that they seem moderately active and have been careful not to overeat. Some authorities believe that overweight under these conditions may be the only evidence of a slight internal gland disturbance which is not yet fully understood. Certainly if one is greatly overweight or underweight, a competent physician should be consulted before any abnormal or unusual dietary program is begun. Sometimes reducing is carried too far for the sake of fashion. Dietary restrictions that lead to pronounced underweight are serious hazards to health. Adolescents especially are likely to undermine their health by starving their bodies at a critical and formative period.

Normal growing children require more food per pound of body weight than do normal adults. Children need extra food for the rapid building of new tissues as well as to supply fuel for their normally greater activity. Many years of observation have proved that, in adolescence, to be a few pounds overweight is an asset to health.

During pregnancy and lactation, women require additional amounts of certain foods to provide for the needs of the developing embryo and for the production of milk for the infant.

Older people usually require somewhat less food than is needed during middle age.

FOOD FOR BODY BUILDING AND REPAIR

The essential constituents of food include proteins, fats, carbohydrates, minerals, and vitamins. No single food is adequate to provide all the essentials of a proper diet for man. Milk probably comes nearest to being a complete food, but even it is not perfect, and an attempt to live indefinitely on milk alone would lead to trouble. Foods vary greatly in their proportions of the essential constituents. For this reason, it is wise to eat a wide variety of foods and to select these so that a balanced diet will be assured.

In order that a diet may be satisfactory it must first of all be palatable. Appetite is necessary for proper digestion and for the best use of food. Good cooking and pleasing flavor therefore become important conditions for good nutrition. Food must also furnish enough caloric value to provide warmth for the body and energy for normal activities. Most authorities are agreed that, for an adult, not less than 10 to 12 percent of the caloric value should be in the form of protein, about 25 to 30 percent in the form of fat, and about 60 percent in the form of starches and sugars. The diet should contain liberal amounts of fresh fruits and vegetables, including some of the green and leafy varieties. Fruits and vegetables and whole cereals are important sources of vitamins and minerals as well as of sugars and starches. Milk, meat, and eggs are likewise essential to a well-balanced diet, since they are important sources of protein and other food essentials. An adequate supply of essential minerals, best provided by a mixed diet, is extremely important. Children need liberal amounts of these minerals to supply the necessary building materials for the skeleton and teeth. Minerals are also necessary for proper structure of soft tissues and for the regulation of many vital processes of the body.

DIETARY DEFICIENCY DISEASES

Poverty, faulty dietary habits, aversion to numerous foods, and the presence of disease are factors that result in suboptimal nutrition for considerable numbers of our population. The chief fault of many American diets is that they provide too little of the essential minerals and vitamins. This fault is due in large measure to the fact that refined foods are consumed in such amounts that the intake of mineral- and vitamin-rich natural foods is lower than it should be.

The occurrence of severe nutritional deficiency diseases in man, other than pellagra, rickets, and possibly infantile scurvy, is rare in the United States. Records of the incidence of such diseases as scurvy and beriberi are not available except as these diseases appear in hospital records or are assigned as the cause of death.

Most authorities accept the point of view that in practically all states of malnutrition in human beings the diet is likely to be inadequate in several food essentials rather than one only and will eventually produce a complex clinical picture, not a clear-cut, simple one such as can be observed with laboratory animals.

Physicians and nutritionists are also beginning to realize that the effects of a prolonged slightly faulty diet may not be detectable for years. The early symptoms of dietary-deficiency diseases in human beings are general and often extremely vague. Prolonged inadequacy of protective foods either from dietary lack, failure of utilization, or increased requirement, produces a variety of border-line states of ill health in advance of severe deficiency states. These border-line states can rarely be defined clearly and rarely appear uncomplicated.

Many people in this country undoubtedly live on diets far below optimum in essential proteins, minerals, and vitamins. Such persons may be quite normal in body weight, or they may even be overweight as a result of eating diets high in fat, sugars, and starches but low in protective foods. Body weight alone is not a reliable index of the state of nutrition of an individual.

Some persons acquire faulty eating habits in early childhood and follow a sort of blind routine or custom in the matter of food selection, never learning what correct diet is. Others follow some preconceived notion as to what foods are good for them instead of putting into practice the sound knowledge available concerning proper food selection. Appetite as a guide in the selection of food is not reliable because it is so largely dependent on custom and attractiveness of flavor rather than on knowledge of the principles of good nutrition. Education in correct dietary habits so that people may learn how to provide themselves with liberal amounts of the protective foods is a very important factor in improving our national health.

Certain diseases are associated with greatly reduced food intakes, poor digestion and inadequate absorption of food, increased requirements, or failure of the body cells to utilize food. In most diseases accompanied by disturbances of the digestive tract, some kind of restricted diet is prescribed by the physician or voluntarily followed by the patient. Such diseases need special attention in order that the food may provide the essentials or that an unbalanced diet may not be continued longer than absolutely necessary. Exercise, growth, pregnancy, lactation, fever, and hyperthyroidism (overactivity of the thyroid gland) are among the conditions known to increase the requirements for at least some of the protective foods.

Physician and nutritionist alike lack the necessary measuring sticks to evaluate the vague symptoms of ill health resulting from malnutrition. Attempts are being made to measure nutritional status in cases where there are no marked symptoms of deficiency, but such attempts are sorely handicapped by inadequate knowledge both of how to make the measurements and of how to interpret such measurements as are made. With present-day knowledge it is possible to measure only a very few of the nutritional disorders that result from a mild deficiency of one or more of the essential food factors. Knowledge of the human requirements for certain of the well-known vitamins and less common minerals is completely lacking. This lack of scientific methods and information obstructs progress in promoting positive and abundant health. So long as mild deficiencies resulting from slightly faulty diets are not detectable, the means of alleviating such conditions through a fully adequate diet will continue to be neglected and what might be called negative health will become progressively worse. Any practical program in human nutrition not directed toward surmounting these obstacles falls short of its real objective, which is to promote positive health and efficiency.

THE FUNCTION OF WATER

Water may or may not be classed as a food, depending on the definition of a food. Certainly water as well as oxygen and foodstuffs is essential to human life. The length of time that life can endure without water depends on several circumstances. For example, men lost while attempting to cross a hot desert without having access to food or water usually die in about 2 to 4 days. There is at least one record of a prisoner who lived 18 days with neither food nor water, but in this case the climate was moderate and the man's activity was slight.

In addition to the water consumed as drinking water and in beverages, the body also receives large amounts from food. Many of our common foods are more than 50 percent water, and even those that from casual observation seem dry contain considerable water or moisture. Besides the water from these sources, some is formed within the body by the oxidation of sugars, fats, and protein. It has been estimated, for example, that as a result of the oxidation of an ounce of fat in the body about an ounce of water is formed.

The bodies of normal persons of the same size do not vary much in water content. Water ordinarily accounts for about 60 to 70 percent of the body weight. Blood, urine, sweat, digestive juices, tears, internal fluids of the eyes, and mucous all contain very large proportions of water.

Water performs many functions in the body. It serves as a vehicle for transporting food and waste products. It assists in the regulation of body temperature. It takes part in many chemical processes. It serves as a lubricant, and to some extent shares the function of body fat in protecting certain organs from external injury.

Normal persons at rest under comfortable conditions of temperature and humidity lose about 25 percent of the heat value of their food by vaporization of water from the surface of the skin and with the air expired from the lungs. This loss of water in a man of average size amounts to about 1½ pints a day; it is spoken of as "insensible perspiration."

When sweating occurs the loss of water from the surface of the skin increases markedly. Athletes during very strenuous exercise have been observed to lose as much as 10 pints of water, chiefly as sweat, within about 1 hour. An average-sized adult normally excretes anywhere from 2 to 5 pints of water a day by way of the kidneys and bowels. Excessive intake of fluids would, of course, increase the amount of water excreted by the kidneys. In summer more water is lost through the skin and less is excreted by the kidneys than in winter.

It would not be possible to give a general recommendation for daily intake of water, since the need varies so widely, depending on climate, clothing, activity, and water content of the food eaten. The satisfaction of thirst usually takes care of the need for water. As a very rough estimate it probably is safe to assume that an average-sized man, comfortably clothed, living in a temperate climate, and doing a moderate amount of work, loses about 6 pints of water from his body every 24 hours. If at mealtimes he ate an appropriate amount of an ordinary mixed diet, including ordinary amounts of fluids, to cover his food requirements, he probably would have provided in this way a water intake of about 4 pints. Thus, in order to replace all the water lost from his body in the same 24 hours he would need to drink about 2 pints, or 4 glasses, of water.

Under normal conditions the average intake of water is believed to run low rather than high, but with the interference of fads both extremes are possible. So-called health rules giving unqualified instructions for the same quantities of water, whether 6 or 20 glasses daily, for all persons, must be regarded with suspicion. The water requirement of a given person can be computed as accurately as can the calorie requirement, but it is affected by so many factors that the requirement under one set of conditions cannot be carried over to an entirely different set. The climate, clothing, amount of sweating, and conditions of health all markedly influence the water requirement.

Restricted water intake leads to diminished appetite and eventually to undernutrition. This is of significance for young children and others to whom water must be offered. Under certain conditions accompanied by abnormally large losses of water, such as continued vomiting, diarrhea, fevers, and copious sweating, the provision of an adequate intake of water may present a real problem.

Unless water is used to flush food into the stomach to avoid chewing properly, there seems to be no adequate reason why satisfying amounts should not be taken at mealtimes. Children should not, of course, be permitted to drink so much water or other liquid just before mealtime or during the early part of the meal that they will be too full to eat the food they require.

Many abnormal conditions such as diarrhea or persistent vomiting may cause the body to be temporarily short of water. During wasting diseases, the body loses water as well as protein and fat. In convalescence these losses are replaced, often with amazing rapidity.

When fat is deposited in the body it tends to replace water, and conversely, as body fat is burned, it tends to be replaced by water. If an obese person undertakes to reduce his body weight by restriction of calorie intake, he is often disappointed to find that his weight does not drop promptyl. The fat in his body actually may be considerably less than it was, but water has been stored in its place. If the caloric restriction is continued the weight will eventually drop, and by almost the exact amount predictable from the degree and period of restriction. A part of the gain in body weight of normal growing children is always water.

Copious sweating involves large losses of sodium chloride, or common salt, as well as of water. Excessive losses of salt by this means, when unbalanced by dietary intake, have been known to cause severe cramps and collapse or heat prostration (*251*). In instances of heavy labor in extremely hot and dry climates, as for example during certain periods in the construction of Boulder Dam, use of salt in the drinking water has been employed to prevent such effects (*278*). Similar temporary measures are sometimes used by cross-desert travelers and for fighters of forest fires. Ingestion of salt tablets is another expedient often advocated for individuals during or following periods of copious sweating.

THE FUNCTIONS OF PROTEIN

Next to water, protein is the most abundant constituent of the soft living tissues. Proteins must always be supplied in food to provide the material necessary for repairing the wear and tear of the soft tissues and for building new tissue.

Before the body can make use of food proteins, they must undergo certain chemical changes in the course of digestion. Proteins are converted during digestion into several distinct and simpler substances, the amino acids, which can pass through the wall of the intestine and be taken into the blood stream. The digestive juices secreted in the stomach and intestines carry certain enzymes, which quicken the processes of digestion and without which proteins could not be digested. There seems to be very clear evidence that enzymes themselves, or at least some of them, are proteins.

The amino acids circulate in the blood, and the body cells select the particular amino acids that they need for building and repairs. Any amino acids that are not required for these purposes are broken down into still simpler substances, of which some are rapidly oxidized and some—chiefly urea—excreted by the kidneys as waste products.

Food proteins differ in the kinds and amounts of amino acids that can be derived from them. The proportions of amino acids present in the soft tissues of the human body are in general more like those in food protein from animal than from vegetable sources. Certain amino acids essential for body building and repair are almost wholly lacking in some of the food proteins. Such proteins are said to be incomplete. Practically all of the 22 known amino acids enter into the composition of the body. However, only 10 are designated "nutritionally essential"—that is, must be present and already formed in the proteins of the diet. The others can be manufactured within the body. Those amino acids lacking in one protein may be fairly abundant in another, and it is consequently recommended that the food provide several sources of protein so that all the essential amino acids may be included.

In addition to the protein deposited in the body by the growth of muscles and certain other tissues, it appears that limited amounts may be stored in the body as a result of eating very liberal quantities of food protein. This so-called storage protein rises and falls in very close association with the intake of food protein. Some authorities believe that such storage of protein toward the end of pregnancy is important for successful lactation.

During exercise the contraction of muscle produces rather large amounts of lactic acid. As this acid is produced the proteins in muscle combine with it in such a way that the acidity does not build up to a harmful degree. This protective function of the body proteins results from the property known as buffer action. As will be pointed out later, buffer action to prevent undue acidity or alkalinity is not an exclusive property of proteins.

A serious and prolonged deficiency of protein in the diet brings about a decrease in the protein content of the blood plasma. This is frequently accompanied by a tendency to form abnormal accumulations of water in the tissue spaces edema particularly in the extremities. Abnormal amounts of fluid may also accumulate in the chest and abdomen, the muscles waste away, and extreme weakness follows.

The so-called war edema, or hunger swelling, which appeared rather extensively in Europe during the World War, was said to be the result of protein deficiency. This condition resulted from prolonged undernutrition when the food consisted chiefly of carbohydrates, very little protein, and almost no fat. Under the circumstances it seems that the condition must have been accompanied by other deficiencies as well.

A condition very much like the war edema has appeared among certain ill-fed populations of this country (*1275*). Severe and prolonged deficiency of protein intake is to be expected among people of the very low income group and in isolated sections of the world where for long periods there may be an abundance of fruits and vegetables but little milk, cheese, meat, and eggs.

An insufficient intake of protein suitable for the purposes of building the new body tissues of children results in subnormal or retarded growth (*747*). Liberal supplies of protein are important during normal pregnancy and lactation. There is also evidence that more infants could be breast-fed if their mothers were provided with ample and suitable kinds of dietary proteins along with other protective foods (*409*).

Protein deficiency may result from causes other than insufficient protein intake. For example, certain diseases may be associated with heavy losses of protein in the urine or with severe hemorrhage, either of which may eventually cause symptoms of protein deficiency. There may also be conditions which interfere with the absorption of the digestion products of food protein.

Gastrointestinal disorders which interfere with proper digestion and absorption of food may lead to deficiency diseases just as surely as an improper intake of food. Some authorities have expressed the idea that the edema of beriberi, caused by vitamin B deficiency, is a sign of protein deficiency caused by disordered functioning of the gastrointestinal tract in the absence of adequate vitamin B.

A daily protein allowance of about 1 gram of food protein per kilogram (2.2 pounds) of body weight is often accepted as a suitable protein standard for the ordinary adult. However, many present-day nutritionists and physicians are convinced that this allowance is insufficient to provide for an optimal intake of protein. Leitch (*676*) has undertaken a thorough revaluation of the experimental data on protein requirements and reaches the conclusion that something like 1½ grams of protein per kilogram of body weight is a better standard for adults.

Low-protein diets were formerly advocated by physicians in the treatment of certain diseases of the kidney, but the present-day trend is quite generally away from severely restricted protein intake in the treatment of renal disease.

THE FUNCTIONS OF FATS

In man, body fat is found in largest amounts under the skin, between the muscles, and around many internal organs. The fat so stored serves as a reserve source of heat and energy when the caloric value of the food is insufficient or for temporary periods when no food is eaten. The accumulation of a certain amount of fat around vital organs such as the kidneys provides considerable protection against cold and injury. Small amounts of fat are also found in the body cells. Certain fishes, notably, the cod and halibut, store practically all of their reserve fat in their livers. Relatively enormous amounts of oils, rich in vitamins A and D, can be obtained from the livers of these fishes.

Certain other fatlike substances (the so-called phospholipids and sterols) are important constituents of the cells of the human body. Some of these form a part of the cell walls, and probably most of them play a part in controlling the passage of food materials through the cell walls.

The fat content of meat is largely determined by animal feeding practices. In the vegetable kingdom, seeds (for example, sesame seed and cottonseed) and nuts are rich sources of fats. Many different kinds of fats have been identified in both plants and animals.

Before fats can be carried to the body cells by means of the circulating blood it is necessary for them to be digested in the intestines with the aid of enzymes. Fats require a longer time for digestion in the stomach than carbohydrates or proteins. For this reason, they are of special importance in delaying the sensations of hunger. This property of fats is frequently referred to as "staying power." A diet practically devoid of fat is very likely to create an abnormal feeling of hunger a few hours after meals. This discomfort was common among refugees of the World War when fats were available in very limited amounts.

A small amount of fat is necessary for the absorption of certain essential foods from the digestive tract into the blood stream (*264*). Carotene, for example, requires the presence of fat for good absorption (*65*).

Certain kinds of fat, containing what are called unsaturated fatty acids, are believed to be necessary for good nutrition. A deficiency of these fatty acids causes a roughness and scaliness of the skin in experimental animals (*175*, *1154*). They are needed only in very small amounts, however, and they are quite abundant in several ordinary fats.

The human race seems to have become accustomed to diets in which the fat content provides about 25 percent of the total calorie intake.

THE FUNCTIONS OF CARBOHYDRATES

An ordinary mixed diet contains about 60 percent of the total fuel value of the food in the form of starches and sugars. In normal processes of digestion, starch and certain of the sugars have to be broken down into one or more of three simple sugars which the body is able to utilize from the blood. These digestive processes are accelerated by enzymes in the digestive juices. An enzyme contained in the saliva begins the digestion of starch in the mouth.

After a meal of ordinary food mixtures, the amount of sugar in the blood rises temporarily and then drops to about 0.1 percent after something like 3 hours. At this level it remains remarkably constant until more food is digested and absorbed. In this way the tissues usually have access to a steady supply of sugar which can be used to produce heat and bodily activity. Carbohydrates are stored in the liver and muscles in the form of glycogen, or animal starch. These reserves furnish the material for keeping the amount of sugar in the blood constant as the cells remove sugar from it. Even with prolonged starvation, the blood sugar does not drop far below 0.1 percent. For this reason, it seems certain that the body can use its stores of fat to make glycogen, which in turn is used to supply sugar to the circulating blood. This explanation of the regulation of the content of sugar in the blood refers, of course, to persons in normal health. Certain diseases—for example, diabetes mellitus—are associated with disturbances in the utilization of sugar by the body.

If the caloric value of the diet is in excess of the body's needs for growth, heat, and activity, the body converts this excess food into fat and stores it. An ordinary individual who regularly takes about 10 percent more food calories per day than are needed probably would store about 20 pounds of body fat in a year. This 10-percent excess could well be provided by an extra helping of dessert.

Besides the sugars and starches, plant foods usually contain another form of carbohydrate, the celluloses. These are insoluble materials which form the cell walls of plants. In man, they undergo practically no change in digestion and serve merely by their bulk and water-holding properties to promote the progress of the food in the intestines and evacuation of the undigested food residues.

THE FUNCTIONS OF MINERALS

Certain minerals, or more properly inorganic ions (the form in which they occur in water solution), are absolutely essential to life. Some of these ions appear to be held in a combination with living tissue. Present knowledge of the functions of inorganic ions in the body is far from being satisfactory or complete. However, intensive studies of their functions and of human requirements for them are under way and steady advance along these lines may be expected.

Some of the inorganic ions that must be supplied by the diet in order to promote normal nutrition include those of sodium, potassium, calcium, magnesium, iron, copper, manganese, sulfur, phosphorus, chlorine, iodine, and probably many others in small amounts, the need for and functions of which we are only beginning to discover. Many of these elements are so widely distributed in both plant and animal foods that little concern has arisen about a shortage of them. The essential inorganic elements that are none too abundantly or widely distributed in ordinary foods are those most frequently involved in deficiency diseases. These include iron, iodine, calcium, and phosphorus.

CALCIUM AND PHOSPHORUS

Calcium and phosphorus in combination form a large proportion of the rigid structures of teeth and bone. Children whose teeth and bones are in process of rapid growth and development should therefore be given foods that will supply liberal amounts of these two minerals. Milk is an excellent source of both calcium and phosphorus.

Calcium is also essential for the clotting of blood and, together with sodium and potassium, for the steady working of the heart and for normal activities of muscle.

Phosphorus takes part in a series of chemical processes involved in the oxidation of sugar, in the activation of certain enzymes, and in the production of buffering acids in the body.

In the discussion of vitamin D deficiency later it will be emphasized that the effective utilization of calcium and phosphorus for bone growth and normal tooth development is dependent on an adequate supply of this vitamin. Vitamin D will not take the place of calcium and phosphorus, nor will these two inorganic elements provided in liberal amounts take the place of vitamin D during growth. Calcium, phosphorus, and vitamin D work together in the important task of building a strong skeleton.

The body of the normal infant is not provided with reserves of calcium and phosphorus at birth, and the period of most rapid growth is immediately ahead. Therefore it is important almost from birth to apply preventive measures against deficiencies of calcium and phosphorus.

In spite of the fact that knowledge of effective measures for the prevention of calcium and phosphorus deficiencies is at hand, there is abundant evidence that a considerable proportion of the general population of all ages does not receive adequate amounts of calcium (*1104*).

The role that calcium deficiency plays in stunted growth has been established for experimental animals. It has been demonstrated in a few human cases by showing that stunted children store dietary calcium at more than normal rates when diets become exceptionally good (*258*). Hunger osteomalacia, or "late rickets," is a severe form of calcium deficiency found in adults, particularly among women of oriental countries. A large number of cases were seen in central Europe during and following the World War (*773*), but only a few have been observed in the United States. However, surveys showing the occurrence and severity of pelvic contractions among women of the United States might reveal facts of considerable import to maternal welfare, since a contracted pelvis interferes with normal childbirth. From such a study in Scotland (*735*), the percentage of cases of contracted pelvis reported ranged from 1 percent among women of the more well-to-do classes to almost 12 percent in congested districts of Glasgow.

The adult body has the capacity for carrying fairly large mobile stores of calcium. To be optimum a diet must keep these reserves well filled at all times. Negative balances of calcium, in which the dietary supplies do not cover the losses by excretion for the same period, are usually taken as a measure of the inadequacy of the diet.

The maternal need for calcium and phosphorus is still greater after the infant begins to nurse than it was during pregnancy. At this stage the infant is building bones at a much faster rate than before it was born. The pregnant or nursing mother whose diet is so deficient in calcium and phosphorus that she must supply these elements from her own tissues to the unborn child or the infant is not safeguarding her own health.

IRON AND COPPER

Iron, although present in the bodies of normal adults only to the extent of about one-fifth of an ounce, is absolutely essential for the formation of hemoglobin, the red pigment of the blood. It seems likely that traces of iron in the soft tissues also take part in the continual oxidations going on there. The liver normally contains a larger proportion of iron than other soft tissues of the body. Infants are normally provided with iron-rich hemoglobin and with stores of iron in their livers at birth. Nature seems to have provided this store of iron to tide over the period when the infant lives largely on milk, a food which contains very little iron. Since the formation of the green coloring matter in leaves requires the presence of iron, green leaves are valuable dietary sources of this mineral. Whole-grain cereals and red meats, especially liver, are also rich in iron.

A reduction in the number of red corpuscles or a deficiency of hemoglobin is usually associated with the condition known as anemia. Not all anemia, however, is due to a deficiency of iron in the food. The manufacture of hemoglobin is a chemical process which takes place continuously and is closely associated with other vital processes in the body. A certain healthy state of the body is essential for the formation of hemoglobin in amounts which will maintain a normal content in the blood. Many diseased conditions such as chronic infection, subnormal functioning of the thyroid gland, nephritis, and scurvy are associated with anemia.

Nutritional anemias resulting from a lack of iron in the diet are found rather frequently among infants, particularly those of the very low income groups (*264*). Some of these cases may be attributed to an inadequate intake of iron by the mother before the birth of the infant (*1106*), and others to a delayed introduction of iron-containing food into the diet of the infant (*1100*).

During growth the body has especially heavy demands for iron to supply the needs for the formation of increasing amounts of hemoglobin in an expanding blood volume. Supplies of iron sufficient to meet the demands of rapid growth must be provided from before birth through adolescence or anemia may be expected to result. That there is an extra demand for iron following losses of blood is obvious.

Copper also is apparently essential for the formation of hemoglobin. At least this has been found to be true in the case of small animals (*323*). Other inorganic elements such as cobalt and manganese perhaps have, in very minute amounts, an influence similar to that of copper. These substances, while aiding in the formation of hemoglobin, probably do not enter into its composition.

One type of anemia, designated as pernicious anemia, is accompanied by a disturbance in gastric secretion. Certain foods in addition to being rich in iron carry an unknown substance, the so-called extrinsic factor, which must react with the gastric secretion to form a new substance essential for the normal production of hemoglobin. A deficiency of this substance would appear to be linked with the occurrence of pernicious anemia.

IODINE

Iodine is essential for the formation of a highly important substance in the secretion of the thyroid gland. This substance (thyroxin) functions in the regulation of the heat production of the body. Practically all of the iodine present in the body is to be found in the thyroid gland. Iodine is fairly abundant in seaweeds and in sea food but can also be supplied adequately by a very small amount of a salt of iodine such as potassium iodide. Actually very little is required by the body, however, and an overdosage of an iodine salt could very easily do harm.

Absence of iodine in the water or food or both brings about an enlargement of the thyroid gland known as simple goiter. This disease is more frequent among women than among men. The disease is more prevalent during adolescence, pregnancy, and lactation than at other times. Simple goiter has been most prevalent in those areas of the United States where there is a deficiency of iodine in the water and soil. These areas include particularly the region near the Great Lakes, certain sections of the Middle West, and parts of the Rocky Mountains.

Simple goiter is far less prevalent in the United States now than some years ago. Part of this improvement is due to the use of iodized table salt and to wider use of deep-sea foods, which are fairly rich sources of iodine.

In some regions where the iodine intake is likely to be deficient the use of iodized water for short periods has been tried. This method of providing iodine is not always satisfactory, because certain individuals living in the community may be suffering from ailments that are aggravated by additional iodides.

It would seem that school children, at least, might be protected from the possibility of an iodine deficiency by having a suitable and safe amount of potassium iodide given to them under proper medical supervision. It can hardly be said that a thoroughly satisfactory method of assuring everyone of a proper intake of iodine has been achieved.

OTHER MINERALS

Magnesium ions are required to promote the activity of at least one enzyme.From results of animal experimentation (*650*, *874*) it is known that a deficiency of magnesium in the diet brings about signs of hypersensitivity and irritability, and during pregnancy and lactation even more severe physical disturbances, such as convulsive seizures.

Manganese probably is required only in very small amounts. A deficiency in the diet of certain experimental animals has been reported to result in sterility of the males and in a lack of maternal care on the part of the female for her newborn young.

While it seems unlikely that a magnesium or a manganese deficiency is common among human beings, the subject deserves further investigation. The correlation of human and animal nutrition has led to great advances for both, since they have a great deal in common. It often happens that what appears as a deficiency disease in animals may be encountered as a result of a disturbed metabolic condition in man.

Sulfur is present in certain essential amino acids which must be provided by food protein and therefore enters into the structure of the soft tissues of the body. A certain combination of sulfur and amino acids, known as glutathione, is very widely distributed in the soft tissues and takes part in the complicated processes of oxidation. Sulfur also enters into the chemical structure of thiamin (vitamin B_1).

Rather large amounts of chlorine in the form of hydrochloric acid are secreted in the digestive juice of the stomach. Here the hydrochloric acid brings about certain changes in foods as a part of normal digestion. Hydrochloric acid is also necessary in order to provide the proper environment for the action of an important enzyme, pepsin, which is concerned with the digestion of food protein. Chloride ions, along with sodium ions, are widely distributed in the body. These two ions in combination are the constituents of table salt—sodium chloride. Man and animals alike suffer salt hunger if deprived of sufficient amounts of this type of salt. Sodium and chloride ions function also in maintaining proper cell pressure—osmotic pressure—which regulates to a large extent the passage of substances through the cell walls. This function is shared with other inorganic ions and with other substances normally present in cells. In the blood and body fluids sodium and chlorine ions take a very important part in maintaining a normal acid-base balance.

Watery fluid, containing inorganic ions of various kinds and nutrients used in processes of repair, growth, and energy and heat for-

mation, surrounds the body cells and is a part of their natural environment.

THE FUNCTIONS OF THE VITAMINS

The vitamins and certain of the minerals have frequently been described as body regulators. Some of these, however, belong just as rightfully to specific body structures as do proteins, and certainly the buffer action of the proteins, mentioned earlier, is a regulatory function. Classification of the essential food constituents by type of function is therefore somewhat misleading.

The vitamins have little in common in chemical composition or properties, but in one respect at least they are alike—each of them is required for normal nutrition only in very small amounts. Some of the minerals too are needed in very small quantities—those that are called trace elements—but there is no danger of confusing them with vitamins, since there is not the remotest resemblance.

The scientific investigation of the vitamins was begun scarcely more than 25 years ago. Because they are new and interesting, and because their presence or absence in the diet provides such startling and dramatic contrasts, the vitamins have been widely popularized. On the whole this is good, though some of the popularization has been at the expense of truth.

The vitamins are essential to health at all ages but are particularly important during the period of growth and development, prenatal as well as postnatal. An inadequate supply of vitamins during this period may cause serious danger to normal development of the bones, teeth, and other body structures.

VITAMIN A

Vitamin A is essential for life, health, and growth. It is indispensable for the maintenance of normal epithelium, a special kind of tissue which serves as a protecting layer of body surfaces. The lining of the digestive tract, for example, separates the living parts of the body from food which has not yet become a part of the body and from waste products which are to be excreted; it is, therefore, strictly speaking, a body surface. The linings of ducts or canals of glands, which carry secretions from the glands to the digestive tract, and the lining of the bladder are further examples of less obvious body surfaces. These epithelial structures undergo marked changes and cannot fulfill their normal functions as protecting layers unless the body is provided with vitamin A.

Vitamin A is essential for the proper formation and normal development of teeth. It forms a part of the visual purple pigment of the retina of the eye. Unless sufficient vitamin A is provided for the formation of this pigment, the eyes gradually lose their ability to see normally in dim illumination—a condition known as night blindness. A severe and prolonged deficiency of vitamin A leads to total blindness.

Carotene, the yellow pigment of carrots and of many other yellow and green plant foods, can be converted by the body into vitamin A. Three separate carotenes and a yellow pigment known as cryptoxanthin normally found in plant foods are thus converted and are frequently called provitamin A or precursors of vitamin A.

A deficiency of vitamin A results in defective tooth formation, in cessation of growth and of normal bone development, in structural change of the epithelial tissues whereby their normal protective function is lost, in night blindness, and, in experimental animals at least, in loss of reproductive powers. The disease of the eyes known as xerophthalmia—the Greek word for "dry eye"—is a result of changes in the epithelial tissues of the eye and the glands that secrete tears. This damage to the eye may become so severe that total blindness results. Recently Mellanby (*779*) has reported that vitamin A deficiency in growing puppies causes structural changes in tissues resulting in deafness.

More detailed information on the pathology of vitamin A will be found in articles by Wolbach (*1246*) and by Bessey and Wolbach (*97*). These articles cite many references to literature on this subject.

VITAMIN B_1 (THIAMIN)

Since the chemical structure of vitamin B_1 has become known, that name has been largely replaced by the name "thiamin." To chemists, the newer name indicates a vitamin that contains sulfur.

Thiamin is an important part of an enzyme (cocarboxylase) which is essential for the normal and complete oxidation of sugar in the body cells. Work on this subject has recently been reviewed by Williams (*1227*). It is quite possible that the several signs of thiamin deficiency which have been observed in man and animals are all results of disordered and incomplete oxidation of sugar. In the absence of complete oxidation of sugar, the production of heat and energy would be decreased and toxic products would accumulate.

A lack of thiamin causes a marked loss of appetite, a loss of tone in the muscles of the intestines, loss in weight, impaired functioning of the nervous system, occurrence of pains and weakness in the limbs, a lowered body temperature, edema, and a slowing of the heart rate.

In countries where polished rice is the principal article of diet, the intake of thiamin is so small that the disease beriberi, or polyneuritis, develops. The symptoms of this disease are largely those listed above, in intensified degree. Milder forms of polyneuritis are believed to be of rather common occurrence as a result of an inadequate intake of thiamin. Polyneuritis seems also to be associated with severe chronic alcoholism. In this case both improper intake of food and disturbed digestion and utilization of food are probably involved.

It is very important that liberal amounts of thiamin be supplied to pregnant and lactating women. Some investigators have reported that the neuritis of pregnancy may be a result of insufficient intake of thiamin. Other workers have found that thiamin is very important for normal lactation. A recent book by Williams and Spies (*1229*) presents a comprehensive review of the clinical aspects of thiamin deficiencies and discusses at some length the uses of thiamin in medicine. The pathology of beriberi also has been reviewed recently, by Vedder (*1164*).

VITAMIN C (ASCORBIC ACID)

Vitamin C is primarily concerned with the production and maintenance of normal material between the body cells (intercellular material). This intercellular material is normally liquid, and the supposition is that it changes to a solid or jellylike state when vitamin C is not supplied in the food. These changes are very marked in intercellular structures of the teeth and bones.

In vitamin C deficiency the cells which produce intercellular substances undergo striking changes. The nutrition and structure of the teeth are affected very early in the absence of vitamin C intake. Later the tiny capillary blood vessels become weakened and cause hemorrhages throughout the body, bleeding of the gums takes place, the teeth loosen, the joints become swollen, and the bones become porous and fragile. These symptoms are characteristic of the vitamin C deficiency disease known as scurvy, which has been known for hundreds of years.

Capillary fragility leading to the appearance of petechiae—small red spots on the skin formed by the effusion of blood—is considered to be one of the earliest signs of vitamin C deficiency provided other causes for capillary fragility are ruled out. Vitamin C deficiency may be regarded as having existed if the capillary strength improves and the petechiae disappear following vitamin C administration.

The vitamin C content of the blood plasma and the excretion of vitamin C in the urine are both decreased in the early stages of vitamin C deficiency.

The pathology of vitamin C deficiency is the subject of a recent review article by Dalldorf (*250*).

Vitamin C is not stored in the body to any appreciable extent, so it is important to provide for regular intake of foods containing this vitamin. Milk is not an important source of vitamin C, and pasteurization causes destruction of most of that present. Therefore it is important, especially in the case of the artificially fed infant, to provide a food source of vitamin C such as orange or tomato juice very early in life. Vitamin C is not very stable to heat in the presence of air or oxygen, so that with ordinary cooking much of the vitamin C value of the food may be lost, particularly in nonacid foods. For this reason it is well to include some tomato juice, citrus fruit juice, or uncooked leafy food in the daily menu. Many commercially canned fruits and vegetables contain about as much vitamin C as the fresh products in spite of the rather high cooking temperatures used. This is because most of the air is removed from the filled cans before the high temperatures are applied.

VITAMIN D

In order that growing children may develop normal teeth and bones it is essential, first of all, that their diets contain liberal amounts of mineral bone-building materials—chiefly calcium and phosphorus. Vitamin D is a further essential, for it aids in the absorption of calcium and phosphorus from the food. If the food is none too rich in calcium and phosphorus, vitamin D enables the body to make the best use of what there is. Vitamin D also corrects or offsets certain unbalanced proportions of calcium and phosphorus in the food which are not the best for purposes of bone building.

The exposure of the body to the rays of the sun creates some vitamin D from a substance present in the skin, but under modern conditions of living this means of providing vitamin D is not always reliable.

In the absence of vitamin D, growing bones do not deposit normal amounts of calcium and phosphorus, and as a result they are easily deformed. The vitamin D deficiency disease known as rickets is often associated with marked deformities of the limbs, chest, and head. By the use of X-rays this disease may be detected long before any deformity of the bones takes place and also before a physician could diagnose it without X-ray examination. In addition to liberal amounts of both calcium and phosphorus, the diets of all children should include suitable amounts of vitamin D from a very early age. Pregnant and lactating women also should receive vitamin D regularly.

Vitamin D does not seem to be so important for the ordinary adult as for growing children and for pregnant or lactating women. Probably the ordinary adult needs only a very small amount of this vitamin and obtains this by eating fish, milk, butter, cream, and eggs, and as a result of a certain amount of exposure of the body to sunshine. It is, of course, highly recommended that pregnant and lactating women receive adequate amounts of vitamin D, because these body functions involve processes of new bone formation and development. Women who get practically no sunshine or outdoor exercise and receive very little vitamin D in their food have been known to lose large amounts of minerals from their bones. In certain regions of India where these conditions are the accepted mode of living for women, this bone disorder, which is called osteomalacia, is frequently found and is exaggerated in pregnant and lactating women.

Adequate amounts of vitamin D may be important for the prevention or arrest of tooth decay (dental caries).

Shohl (*1058*) has recently summarized present knowledge on the physiology and pathology of vitamin D in a review article.

VITAMIN E

In animals, vitamin E has been found essential for the promotion of late stages of growth and for reproduction. The only evidence we have of the function of vitamin E in human beings is that repeated abortions in women have been reported in a few cases to have been followed by normal pregnancies after administration of concentrated preparations of vitamin E from wheat-germ oil. Vitamin E is so widely distributed in foods that it seems unlikely that a deficiency could be a matter of great concern in human nutrition.

VITAMIN G (RIBOFLAVIN)

Riboflavin is a yellow water-soluble pigment widely distributed in the tissues of both plants and animals. This vitamin, it is believed, plays a part in the oxidative processes of all living cells. In this capacity it is combined with a protein to form an enzyme.

A deficiency of riboflavin in animals is characterized by cessation of growth, marked loss of hair, nutritional cataract, appearance of a skin disorder, and a general failure in physical well-being. Riboflavin is widely distributed in natural foods. It seems unlikely that a deficiency would often be encountered without the appearance of other deficiencies at the same time.

NICOTINIC ACID

The primary function of nicotinic acid in the body appears to be its part in the formation of a substance that plays a vital role in oxidation.

Lack of nicotinic acid or of certain very closely related chemical substances which occur in many natural foods would seem to be the deficiency of first importance in pellagra, though this disease may be the result of several dietary deficiencies. Chronic alcoholism often results in the development of a condition very similar to if not identical with pellagra. In these cases, it is believed that bad food habits and poor condition of the digestive tract account for the dietary deficiency, or for the inadequate utilization of food, or both.

Pellagra occurs often in outbreaks resembling epidemics in localities with restricted food conditions. It is not necessarily limited to any particular geographical areas, however. Since its cause is a dietary deficiency, it may crop out anywhere at any time. In the United States this disease appears most frequently in the late spring following a winter during which the food supply has been monotonous and defective. Pellagra may develop at any age, and while it is most prevalent in families with very low incomes, it is not restricted to these. In certain well-to-do families the disease has been brought about as a result of peculiarities in food choice, food fads, gastrointestinal diseases, chronic alcoholism, or other conditions which have made the diet unbalanced, restricted, monotonous, and faulty.

Pellagra is characterized by a certain type of skin eruption affecting especially the backs of the hands and forearms, the face and neck, feet, and genitalia. The severity of the disease is increased by exposure to sunshine. The disease is also accompanied by digestive disturbances and nervous disorders. About 2 percent of pellagrins develop mental disturbances requiring institutional care.

The specific food deficiency of pellagrins—nicotinic acid, or some closely related substance—is found abundantly in fresh lean meats, milk, yeast, and many of the common vegetables. It would seem, however, from the very nature of the food restrictions which produce pellagra, that a typical pellagra-producing diet is grossly defective in more than one food essential. A study was reported (*1103*) of the food supply and pellagra incidence in 73 South Carolina families in 1932. In comparison with the diet of nonpellagrous families of the same region, the diet of pellagrins was quite low in several vitamins and essential minerals. The best way to prevent pellagra and promote health is to supply an adequate balanced diet, giving special attention to the use of liberal amounts of the protective foods.

Sebrell (*1020*) has recently reviewed the present knowledge on the prevention and treatment of pellagra.

VITAMIN K

Vitamin K, a newly discovered fat-soluble vitamin, has recently been obtained in highly concentrated form from alfalfa leaves. It occurs abundantly in green leafy vegetables. Small amounts of this vitamin have been found necessary in the diets of chicks in order to prevent hemorrhages in the muscles and under the skin and to maintain a normal blood-clotting time. In man a slow blood-clotting time has been observed in persons suffering from obstruction of the bile duct. A few preliminary experiments have indicated that the administration of concentrated preparations of vitamin K is beneficial in improving the blood-clotting time of these patients, provided bile or bile salts are administered at the same time. Presumably the bile salts are essential for the absorption of vitamin K from the intestines.

OTHER VITAMINS

Several other vitamins than those discussed above are known to be present in natural foods, and some of these have been isolated. However, the functions of most of them are known only as a result of observations in the feeding of animals. Knowledge of their functions in human nutrition must await further study.

FOOD AND LONGEVITY

Longevity is not a desirable gift except as it may enable us to live full and useful lives for a longer time. Some people remain vital and mentally active to 80 or more years of age. Others are broken in health at 30 or 40. If longevity is to be a blessing, it must be accompanied by a prolongation of the fullness and the prime of life.

For the most part knowledge of the conditions which promote longevity has been gained by observations of small animals. Only by the use of animals that normally have a much shorter life span than man is it possible to note the effects favorable to longevity and to continued health and vigor over a period of many generations. Such studies are interpreted in terms of the rate of growth of the young, adult size attained, length of the reproductive period, degree of success in bearing and rearing young, and the length of time that elapses between completion of growth and the appearance of senility.

McCollum and his associates (*722*) have found as a result of about 25 years of study that when domesticated rats are fed a diet planned with careful attention to all the principles of the newer knowledge of nutrition the animals have the maximum of vigor and vitality at all stages of development. When the diets are defective in any way the animals show early signs of senility, other signs of poor health, or deformities, the nature of which depends upon the particular dietary defect.

Sherman and his coworkers (*1051*) have found that diets already adequate to support an average state of nutrition and health can still be greatly improved by applying the principles of good nutrition. They estimate that the present life expectancy of 70 years could be increased to an average span of 77 years without any new discoveries, if people simply took advantage of the present knowledge of nutrition. They also found that the benefits of better-than-average nutrition were carried over to succeeding generations.

McCay and his associates (*716*) of the New York (Cornell) Agricultural Experiment Station found that rats retarded in growth and development by severe restriction of calorie intake lived longer than animals allowed to eat as much food as they liked. The retarded animals appeared to remain young longer, too, but they were more sensitive to such influences as sudden and severe changes in temperature, and when finally they were given unlimited quantities of food they never attained the same size as normally fed animals. In another experiment (results unpublished) some important observations were made on normally nourished animals; starting at middle life, some were allowed to grow fat and some were kept thin. The investigators took special pains to provide both groups with adequate intakes of the protective foods—the vitamins and essential minerals. The results showed very clearly that the thin animals outlived the fat ones. This seems to support the adage "A lean horse for a long race." But it must not be forgotten that thinness can be carried to an undesirable extreme with grave danger to health and life. Emergencies often arise when reserves are urgently needed to tide over a crisis.

According to combined records of 40 life-insurance companies, the lowest death rate at middle life is found among persons weighing a few pounds less than average. A moderate amount of overweight before the age of 30 to 35 is generally considered favorable to health, but overweight after 35 and in middle life is a menace to health and longevity, besides adding a burden of extra pounds. It generally indicates faulty living habits.

RELATION OF DIET TO DENTAL CARIES

The occurrence of dental caries, or decay of the teeth, has been observed in man for centuries. In a recent Nation-wide survey (*784*) in which over 1,400,000 children from 6 to 14 years of age were examined, it was found that 50 to 75 percent had carious teeth, with an average of at least 2 to 3 cavities per child in the worst sections.

In the remote interiors of east Greenland, where there was little contact with outside civilization, it was found (*905*) that only about 4.5 percent of the natives had caries. Around a trading station established 15 years ago the incidence of caries was about 25 percent, and near a station established 45 years ago, 40 to 50 percent of the natives had carious teeth. It seems quite evident that dental caries is definitely favored by certain conditions of modern civilization.

The effect of diet on the development of dental tissues and the liability of such tissues to disease have been studied extensively by Mellanby and her coworkers. It was found (*780*) that susceptibility to dental caries in man was primarily dependent upon the structure of the teeth—the more perfect their structure, the less their liability to decay.

Since the hard structures of teeth consist largely of calcium and phosphorus, it is obvious that the building of good tooth structures requires adequate supplies of these inorganic elements. Mellanby and her coworkers furthermore affirm that an adequate supply of vitamin D is of very special importance in the development of sound tooth structures and that diets high in cereal content may be conducive to caries unless adequate supplies of vitamin D are provided. A deficiency of vitamin A has been reported (*781*) to cause degenerative changes in the dental nerves and may for this reason be partly responsible for dental caries in some cases. Wolbach and Howe (*1249*) have shown that a deficiency of vitamins A and D in the diets of experimental animals causes a disordered calcification of the hard tissues of the teeth.

Wolbach and Howe (*1248*) also made some very detailed studies of the effects of vitamin C deficiency upon the tooth structures. They found that within a very few days after experimental animals were deprived of vitamin C the layer of specialized cells between the tooth pulp and the hard tissues of their teeth, which is essential for the maintenance of the hard tissues, failed to function. The normal function of this layer of cells could be reestablished by administration of vitamin C, but the normal strength of such teeth is presumably never fully regained.

Many authorities are convinced that a sound tooth structure which will withstand the ordinary pressures involved in mastication is the best possible insurance against mechanical injuries that would render the teeth susceptible to decay. In order, then, that good tooth structures may develop and be maintained, it is highly important that the diet contain adequate quantities of calcium and phosphorus and of vitamins A, C, and D.

Vitamin A is especially important for the proper formation of the framework of the teeth before any extensive calcification takes place. Since this framework is being developed in the infant several months before birth, the mother should be provided liberally with vitamin A. In order that the teeth may continue to develop properly, adequate amounts of calcium, phosphorus, and vitamins C and D are very important.

There is some difference of opinion as to whether or not the occurrence of dental caries is increased during pregnancy and lactation. Many of the observations on the occurrence of caries during pregnancy and lactation have not been correlated with the mother's diet, frequency of childbearing, and general state of health. As a safeguard, therefore, the mother should certainly be provided with liberal amounts of protective foods, especially calcium, phosphorus, and vitamins A, C, and D.

Certain diseases, notably rickets and prolonged fevers, are often associated with inadequate intake of protective foods and are in consequence predisposing causes of dental caries.

The widespread use of diets containing large proportions of highly refined foods which contribute chiefly starches and sugars may, by reason of excluding an adequate intake of protective foods, be a predisposing factor in the prevalence of dental caries in our modern civilization. Other factors, such as inherited physical constitution and fermentation of carbohydrate food residues around the teeth, may be contributory in dental caries. Whatever the causes, the results of observations on children are unanimous in showing that an improved diet in general increases resistance to tooth decay.

DIET AND RESISTANCE TO INFECTION

A normal healthy body possesses remarkable powers of warding off or overcoming many infections and of withstanding the ravages of disease.

Marked underweight is usually one of the obvious and very common signs of undernutrition. The Life Extension Institute gives this warning with regard to underweight and disease resistance: "Pronounced underweight before the age of 25 is an unfavorable condition, as it is often associated with lack of resistance to pulmonary affections and to other diseases of youth"; and again:

> When underweight is associated with a tendency to frequent colds and there is a condition of debility, anemia, or general malnutrition, it is, at any age, an unfavorable symptom, especially if there has been recent loss in weight. Under such conditions, dieting should be directed to improving nutrition and inducing a gain in weight.

Certain dietary essentials have from time to time received hopeful consideration as special agents which might be effective in combating or resisting infections. Vitamin A is one of the most notable of the group, so much so that for a time it was frequently referred to as the "anti-infective vitamin." It has already been pointed out that a marked deficiency of this vitamin eventually leads to injury of certain specialized cells—the epithelial cells—which form protective layers for the body surfaces. This change affects, for example, the skin and linings of the respiratory and digestive tracts. As a result of this injury the normal function of these cells is lost. Animals deprived of vitamin A have been reported to develop infections very rapidly. The chief function of vitamin A seems to be to keep the body surfaces (the skin and mucous membranes) healthy so that they form a natural and effective barrier between the blood stream and the disease-producing organisms of the outer world in contact with them. There is no scientific proof that vitamin A is a special agent for combating or resisting disease-producing organisms after they have once invaded the body.

These statements do not mean that the use of fish-liver oils, which has become rather widespread for both children and adults and is especially recommended during the winter months, has no sound basis. As a matter of fact, a fish-liver oil rich in vitamin A and vitamin D should be given regularly to children. Adults whose regular diet provides liberal amounts of whole milk, butter, eggs, and leafy green and yellow vegetables would probably not be benefited by further provision for vitamin A. If, however, the proportions in the diet of these food sources of vitamin A are to be limited for any reason, the intake of small amounts of fish-liver oil would furnish a measure of safety. The fish-liver oil also contains vitamin D, which it is well to provide during those seasons when the body has little opportunity for the manufacture of this vitamin by means of exposure to sunshine.

Other dietary essentials are being studied as possible agents in increasing resistance to infection, but the results are as yet not conclusive.

It is generally accepted that natural resistance to disease—not resistance acquired—is dependent upon and varies with the nutritional state of the body. Therefore the best advice that can be given regarding diet to one interested in maintaining health and vigor is to select food in accordance with such recommendations as those outlined in another article in this Yearbook (p. 321) and to eat the proper quantities to avoid serious underweight or marked overweight.

FOOD HABITS, OLD AND NEW

by Hazel K. Stiebeling[1]

THERE are striking examples in various parts of the world of the effects of good and bad food habits on large groups of people. Food habits in the United States have similar effects on the health and the physique of Americans. In general, we are probably ahead of most other countries nutritionally—yet the dietary picture in the United States leaves much to be desired.

THE ABUNDANCE and variety of man's food depend upon his control over environment. For primitive tribes this meant success in hunting and fishing, and discovery and discriminating use of roots, leaves, fruit, and seeds of wild plants. Later, as animals were domesticated and agriculture got under way, control over environment came to mean good management of crops and flocks. Today for a large part of the population, especially for city dwellers, it has an additional meaning—purchasing power, or the ability and the opportunity to produce goods or render services that can be exchanged for the varied products of agriculture, fisheries, and the food industries.

EVOLUTION OF FOOD HABITS

If early man chanced to inhabit a seacoast region, he ate quantities of shellfish and other sea food. If he lived inland where nuts, wild roots, and seed-bearing grasses were abundant, such foods were used. No doubt in all localities birds and their eggs and such other animal foods as were available were eaten. In the Arctic regions, now as in the past, food consists chiefly of animal products, because that is the only kind available in quantity. In the Tropics, where vegetable food is abundant and animal foods spoil quickly, plant products are and always have been of great importance in the diet. In temperate zones many kinds of food are obtainable, and it seems reasonable to suppose that in these regions all classes of food have always been eaten as they are today.

Race experience teaches that man can survive on many types of diet and that he is fitted to be omnivorous—an eater of both plant and animal foods. At times he may have fared as a vegetarian: "Every herb yielding seed and every tree in which is the fruit of a tree yielding seed, to you it shall be for food." At times he may have subsisted on a mixed diet: "Every beast of the earth, every bird of the heavens, all the fishes of the sea, every moving thing that liveth shall be food for you; as the green herb have I given you all."

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Choice or selection within the available supply has until recently been governed largely by tradition—the accumulated wisdom of ages of experience. Not all food customs and food taboos had their origin in the desire for social welfare, however. At times they reflected the power of the strong to gratify personal desire for delicacies or choice bits. But there were limits to selfishness. Continuance of family or race depends upon having enough food of suitable kinds to permit reproduction, the successful rearing of the young, and the maintenance of enough strength and vitality to escape accident, to win in conflict, to endure the elements, and to build bodies fairly resistant to disease. Hence diets that were traditional over generations possessed at least survival value.

Some traditional diets are better than others. For example, the superiority of diets of northern India over those in the south and east of that great country has often been noted. McCay (*717*)[2] found the pastoral peoples of northern India to be superior in health and strength to those in other regions. His impressions are said to be in line with reports of British Army officers to their Government as to the fitness of men from different parts of India for military service. McCarrison (*712*, *712a*) compared the response of laboratory animals fed upon diets like the milk-and-vegetable food of the "stalwart resolute races of the North of India" with those given diets representing the food of the "toneless, supine, and poorly developed people" of the south and east. The first-mentioned diet included whole wheat, milk, legumes, vegetables, and some meat; the latter, a large proportion of polished rice, some legumes, vegetables, and fruit, but little or no milk and meat. He found that animals subsisting on the latter diet exhibited a large proportion of the maladies included in the calendar of human ailments, whereas animals on the former diet were remarkably free from ill health. In commenting upon these Indian diets, the Department of Physiology of Rowett Institute (*828*) points out that whereas the diets of the northern Indian peoples are twice as rich in calcium as the diets of the well-to-do Hindu, and eight or nine times as rich as those of the poor Hindu, they still are capable of improvement in this respect.

Differences in the quality of traditional diets are also indicated in reports published by the British Medical Research Council (*877*) on the physique and health of two tribes living in Kenya, Africa—the Masai and the Akikuyu.

> The diet of the former consisted to a large extent of milk, meat, and raw blood, and that of the latter, mainly of cereals, roots and fruits, the bulk of the diet being cereals.
>
> Physical measurements showed that the full-grown Masai male is on the average, 5 inches taller and 23 pounds heavier than the full-grown male Kikuyu, and his muscular strength, as determined by the dynamometer, is 50 percent greater.

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[2] Italic numbers in parentheses refer to Literature Cited, p. 1075.

> Marked differences were found in the incidence of disease in the two tribes, bony deformities, dental caries, and anaemia, pulmonary conditions, and tropical ulcer being much more prevalent amongst the Akikuyu. On the other hand, intestinal stasis and rheumatoid arthritis were more common amongst the Masai.

The chief points of difference reported in chemical composition of the two diets were that the diet of the Masai was relatively high in protein, fat, and calcium, while that of the Akikuyu was high in carbohydrate and low in calcium. Although the authors do not contend that diet is the sole cause of differences in health and physique, they conclude that improvement in these respects might be brought about by increased consumption of green vegetables by both tribes, and of milk by the Akikuyu.

It is generally conceded that compared with those of other countries diets in the United States are generous and that the range in variety of food products is unusually large. Dietaries now in use in the United States combine the many customs and food habits of the various racial and national groups that have helped to make up the population. While American heritage derives chiefly from northern and western Europe, it has been more or less influenced by other groups. The American Indian has contributed much. Immigrants from southern and middle Europe have also left their mark. In the Southwest the influence of Mexico and in the far West that of the Orient are evident.

Improvements in stature and body build among immigrants to the United States have been attributed to the better diets obtainable here. The second generation of Japanese in California (*935*, *1094*) and of Europeans in the larger American cities are of larger stature and better physique than their parents (*697*, *736*). At the same time, American women entering colleges are found to average more than an inch taller than those in the same colleges 30 years ago (*140*, *824*). The average stature of Harvard men has increased about 2 inches in the last 60 years (*140*, *697*).

TRENDS IN DIETARY HABITS IN THE UNITED STATES

Present-day diets in the United States differ markedly from the diets of a few generations ago. These changes are due to a number of factors. Available food supplies have broadened in scope. Methods of cultivation of food crops and of feeding of livestock have improved. New methods and increased facilities for the storage and transportation of food have been developed. Marked changes have been made in the processing and manufacturing of food products. In addition, modern facilities for communication, contact with neighbors having different cultural backgrounds, travel at home and abroad, the printed page, and the radio have all helped to develop an interest in a wide variety of food combinations and flavors. Not only are diverse tastes tolerated, but in modified form they are widely adopted. As a result of these many influences, there have been great changes both in the quantities of different kinds of food consumed and in the nature of the available food products.

Few quantitative data are available to show the magnitude of this change in diet. Its trend and character are shown by studies of family diets made during the last half century. W. O. Atwater, who for so long was in charge of the nutrition investigations of the United States

Department of Agriculture, was a pioneer in dietary studies in this country. Between 1885 and 1905, he and his coworkers accumulated much information regarding the foods eaten by individuals and groups living under many different conditions. Following this work, the next most important dietary investigation probably was that of Sherman and Gillett, who in 1914–15 obtained detailed and accurate information from 92 low-income families, most of whom lived in New York City. Since then many dietary studies have been made, some in one part of the country, some in another, each adding to our knowledge of American food habits. Two of the most extensive investigations so far attempted have been made by the Bureau of Home Economics. One deals with the content, nutritive value, and economy of the food purchased by families of employed wage earners and clerical workers in 43 industrial centers in 8 major geographical regions of the country (*1104*). It was based on dietary records obtained during the period December 1934 to February 1937 by the Bureau of Labor Statistics in connection with their study of income and disbursements of wage-earner families. The other deals with the food consumption of different-sized families living in cities, villages, and on farms in different parts of the country, and classified by income. These data were obtained in connection with the consumer purchases study made by the Bureau of Home Economics and the Bureau of Labor Statistics in cooperation with the National Resources Committee, Central Statistical Board, and Works Progress Administration.

Changing dietary patterns can be quickly seen from the proportion of calories derived from the major groups of food, as shown in table 1. During the period covered by this table families at each of three important levels of food expenditure have put decreasing emphasis on grain products and meats, and a greater emphasis on fats, sugars, fruit, succulent vegetables (other than potatoes and dried legumes), and milk. The proportion of calories from milk, cheese, fruits, and succulent vegetables actually has been doubled in the last 50 years. Larger and more varied market supplies have been made possible not only by increased production but by a highly developed system of food preservation and distribution.

About three-fourths of the calories in family diets prevalent in this country are derived from grain products, meats, refined fats, sugars, and tubers. The nineteenth-century invention of the steel-faced plow and the modern roller-mill process of milling wheat greatly stimulated cereal production. Cereal grains not only serve directly as food for man, but, as feed for animals, they are used to increase the supply of meat and fat. Pork production is concentrated largely in the Corn Belt, and much of the beef is at least finished (fattened) in the Corn Belt, instead of coming to market directly from the western grass ranges, as formerly.

The consumption of sugars and fats is even greater than the figures in table 1 indicate, because the sugar and fat columns do not include the quantities of these foods consumed in the form of commercially made baked goods, or the sugar purchased in canned fruits, confectionery, and beverages. There was an increase in the consumption of confectionery and soft drinks in the decade following the World War. Also to some extent sugar consumption accompanies fruit consumption, just as fat and oil consumption tends to accompany increased use of vegetables.

TABLE 1.—*Trends in village and urban dietary patterns as shown by proportion of calories derived from specified groups of food* [1]

Food expenditure a person a week [2] and period	Proportion [3] of calories derived from—								
	Grain products	Meats,[4] poultry, fish, eggs	All fats [4]	Sugars and sweets	All vegetables and fruit	Milk, cheese	Milk, cheese, fruits, and succulent vegetables	Grain products, meats, poultry, fish, fats other than butter, sugars, potatoes, and dried legumes	Milk, cheese, all vegetables, fruit, butter, and eggs
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
$1.25–$1.87:									
1885–1904	41	22	13	10	9	5	8	84	22
1905–14	42	18	12	9	12	7	10	83	26
1915–24	37	13	15	12	14	9	16	77	30
1925–34	37	12	16	11	13	11	17	78	29
1935 and later	34	12	18	12	13	11	16	77	31
$1.88–$2.49:									
1885–1904	34	25	15	10	10	6	9	81	26
1905–14	40	18	13	10	13	6	11	79	29
1915–24	36	15	15	12	13	9	15	75	32
1925–34	36	12	16	11	15	10	16	78	31
1935 and later	31	13	18	12	15	11	18	74	34
$2.50–$3.12:									
1885–1904	38	24	12	10	10	6	9	83	24
1905–14	35	25	12	10	11	7	11	84	23
1915–24	30	13	18	12	16	11	17	72	38
1925–34	32	15	16	11	15	11	19	73	34
1935 and later	30	15	18	12	14	11	18	73	34

[1] Based on data from family dietary studies, 1885–1937.

[2] Adjusted to 1935 price levels by use of retail food-cost index of the U. S. Bureau of Labor Statistics.

[3] The first 6 groups are mutually exclusive and include all articles of diet. The last 3 groups are not mutually exclusive.

[4] Salt side and bacon are included with fats.

SIGNIFICANCE OF RECENT TRENDS IN FOOD HABITS

In discussing dietary patterns of this country McCollum (*725*) writes:

> We have been trying an experiment in human nutrition on a Nation-wide scale, with a dietary which is of a kind which no people in history ever tried to live upon before. There was no way in which the results of such an experiment could have been foretold, for the dietary properties of individual foods were not understood, and the nutritive requirements of the body were essentially only half understood. It is possible, however, after approximately two generations of experience with a diet of the white bread, meat, sugar and potato type, with small, but generally inadequate additions of other foods of kinds which are capable of correcting the defects of the principal components of the food supply, to attribute certain unfortunate effects definitely to an unsatisfactory dietary. All the information available seems to warrant attributing in great measure the high incidence of malnutrition among children of pre-school and school ages, the faulty bone growth, bad teeth and faulty posture, to inadequacies in our national dietary, and to perverted appetite resulting from pampering and the formation of a liking for sweet foods.

Forty to fifty years ago more than 80 percent of the food calories in American diets were derived from the grains, meats, fats other than butter, sugars, potatoes, and mature legumes. The proportion is still well over 70 percent, even though consumption of milk, fruits, and the succulent vegetables—foods noted for their mineral elements and vitamins—has markedly increased.

During this period also, certain food preferences have developed that affect dietary adequacy. A modern standard of fastidiousness leads many people to prefer the lean-muscle cuts of meat to the organs of animals that race experience had taught primitive peoples to prize highly. The association of goodness with richness in fat has induced many to prefer cream and butter to skim milk, which, while lacking in fat and vitamin A value, is nevertheless as rich as whole milk in protein, in the much-needed calcium, and in many other water-soluble nutrients. Some food-processing practices, such as a high degree of milling of wheat, refining of cane sugar, and bleaching of vegetables, have stripped products of certain nutritive values while enhancing their keeping qualities in storage and increasing whiteness, which appears to have strong psychological appeal because it is associated with purity.

Thus certain trends in dietary practices tend to impoverish rather than enrich diets from the nutritive standpoint. To a greater or less degree these tend to offset the beneficial effect of increased consumption of milk, green-colored vegetables, and fruits. In consequence, diets are still relatively short in calcium and in vitamins A, B, and C.

Milk, green leafy vegetables, and fruits have long been known as "protective foods" because of their ability to compensate for certain of the shortages likely to characterize American diets. To bring current food habits into line with present knowledge Sherman (*1044*) suggests:

> (1) Let at least half of the needed food calories be taken in the form of the "protective" foods—milk and its products, fruits, vegetables, and eggs.
>
> (2) Of whatever breadstuffs and other cereal or grain products are eaten, let at least half be in the "whole grain," or "dark," or "unskimmed" forms.

To put this suggestion into practice would constitute a major shift in American food habits. At the present time less than one-third rather than half of the food calories tend to come from milk and its products, fruits, vegetables, and eggs, and less than a fifth rather than half of the breadstuffs are in whole grain or dark forms.

CHANGES IN NATIONAL DIETARY HABITS

Shifts in dietary practices tend to evolve slowly. However, significant changes took place during the period 1915–24. Many factors contributed to this. Among these may be mentioned shifts in relative food prices; Nation-wide propaganda during the World War for wheatless and meatless days to conserve these foods for military purposes; the enactment of prohibition; the dramatic and widely publicized discoveries of the vitamin values of food; and a growing appreciation of the significance of food to health. While it takes effort to change long-established food habits, under the impetus of a deep urge people will modify them if they can afford it. Because people like the foods to which they are accustomed and a taste for new or strange flavors or new food combinations must usually be cultivated, they will seldom take the trouble required to make a change unless there is a strong motive.

Chief among current motives for changing dietary habits are fashion *and health. In food as in clothing there is a tendency to copy the styles set by the accepted leaders in social groups. Such styles may or may not be in accord with present knowledge of dietary requirements and food values.*

The health motive for changing diet habits would be strengthened if obvious manifestations of the effect of diet on nutritional well-being followed day-by-day food consumption with dramatic swiftness. One reason that this is not the case arises from the ability of the body to store certain reserves during periods of plenty to be drawn upon in times of dietary poverty. This provision tends to free one from the tyranny of exactly meeting the physiological requirements of the body from day to day. But it tends to foster a treacherous sense of security that whatever regimen seems to have served well enough in the immediate past will continue to do so indefinitely. Also it adds to the difficulty of convincing the layman that the science of nutrition, as Sherman says (*1044*), can offer to a much larger part of the population a longer life, an earlier and longer prime of life, and more buoyant health through the whole life cycle such as only the most fortunate now enjoy.

The last half-century has seen much progress in the science of nutrition—has seen, indeed, the acquisition of practically all of the knowledge we now have. Still more facts are needed, however, before food requirements for the highest physical and mental response can be outlined with certainty. This knowledge can be obtained only through long-continued, painstaking, and properly planned research. Yet enough has already been accomplished to convince many groups among the general public of the importance of food to well-being, and to enable scientists to mark out the broad lines of advance in applying the findings. Widespread improvement in nutrition would result if present knowledge, incomplete and far from precise though it is, were widely disseminated and put into common practice.

The discrepancy between current popular diets and the type of diet that our present knowledge of foods and nutrition would recommend seems to be due to several factors. Chief among these are food habits, some old, some comparatively new; a too general lack of appreciation of the importance of an adequate diet; and inadequate knowledge of food needs and food values in relation to cost. Equally important is the lack of purchasing power on the part of many urban families, and, especially in the case of rural families, insufficient success in planning and carrying out a food-production program designed to complement food purchases.

CAN FOOD HABITS BE CHANGED?

by Paul E. Howe[1]

GETTING a good diet is not always a matter of money. In fact, it is more often a matter of changing bad food habits to good ones. Every mother as well as every dietitian knows how difficult this is. Here are some suggestions on how to accomplish it. No problem in the whole field of nutrition is more important.

MAN USES FOOD as a means of satisfying many emotional needs, which are so closely related to his physiological needs that unless they are met he fails to get the most from his food. He enjoys and even demands variety, not only in foods themselves, but in methods of preparing them; he wants foods that appeal to his eyes and his senses of taste and smell; he wants to eat in pleasant surroundings. Traditionally, partaking of food with other persons has been of such social importance that the emotional satisfaction derived from eating has often overshadowed the actual physiological needs supplied by food. These factors, together with food habits that have been established in connection with them, greatly complicate the attainment of an adequate diet.

Dietary habits are double-edged. If they are good, they help us to resist changes to other, possibly less satisfactory, diets. If they are bad, they act as a barrier to the adoption of more satisfactory diets.

Primitive man was chiefly concerned with securing a sufficient food supply. In modern life not only the increased production of food, but its manufacture, sale, transportation, distribution, selection, and preparation have made a greater variety of foods available and have changed the character of many common foods. Present-day facilities for travel have tended to break down local food habits and to increase the demand for products of distant areas. Scientific research and exploration have introduced many interesting and nutritious new foods that offer opportunities to add variety and interest to meals.

The ability to transport foods easily and economically has led to marked changes in food habits. It has encouraged the production of particular crops in the areas best adapted to grow them. It has enriched the dietary in periods of normal production. In times of crop failure in one area, it has made possible the procurement of food produced elsewhere.

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The ability to store foods over long periods and to make use of manufacturing processes that preserve or increase palatability or attractiveness have had similar influences. On the other hand, storage and manufacture have created new problems. They have modified the nutritive value of natural foods by removing, reducing, or destroying some of the nutritive factors and concentrating others. These changes in the nutritive value and palatability of foods have in turn created new wants.

FOODS FURNISH THE ESSENTIAL NUTRIENTS

The nutritive requirements of man are determined and expressed in terms of essential components of foodstuffs such as carbohydrates, fats, proteins, vitamins, minerals, and water, or the energy derived from some of these components. The necessary quantities of the various factors vary with the size, age, and activity of the individual and with the external conditions to which he is subjected. In arranging the diet, however, man usually thinks and plans in terms of actual foods—meat, potatoes, milk, salads, for example—rather than of essential nutrients. Natural foods usually contain some of all of the necessary nutrients, although the amount of a particular nutrient may be so small in a particular food that in ordinary quantities the food may scarcely be considered a source of it.

It is possible to satisfy nutritive requirements from a large variety of foods. To meet different individual, group, or regional tastes, to utilize available foods to the best advantage, and to modify diets successfully, it is important to know the more important contributions that various foods make to the diet. This has been simplified by classifying foods into groups that are similar in composition or that are particularly good sources of some nutrient or nutrients. Thus, for example, meats, milk, and eggs are sources of protein of good quality; milk, the leafy vegetables, and dried legumes are sources of calcium; the green and yellow vegetables and butterfat are sources of vitamin A and carotene. Such groupings are discussed in detail in the article on Planning for Good Nutrition (p. 321). Using this knowledge, it is possible to express nutritive requirements in terms of quantities of types or groups of foods.

This grouping of foods has a further advantage in that it does not give undue emphasis to any particular food. It permits elasticity in selection to meet a variety of conditions and tastes. In the course of scientific investigation, the discovery of a nutritive factor sometimes becomes associated with a particular food. The application of such knowledge often leads to a misunderstanding of the possibilities of the use of other foods. It is important, therefore, in presenting information on nutrition, to mention more than one source of each nutrient factor.

Fluid milk, for example, is the standard source of calcium. The daily consumption of a quart of milk by a child or a pint by an adult is an assurance of an adequate calcium intake. But those who do not like or cannot get fluid milk may substitute canned or dried milk, cheese, an extra amount of leafy vegetables, or even calcium salts and still meet their daily calcium requirements.

Carotene, one of the precursors of vitamin A, is chiefly responsible for the yellow color of vegetables and milk. But carotene is also present in the green leaves of plants, although masked by the green color. Any of the yellow or green vegetables, especially the leafy vegetables, or the yellow foods derived from animals, may be selected as a probable source of vitamin A.

An example of the value of substituting one food for another for economic reasons was shown some years ago by A. F. Hess. At a time when lime and lemon juice were the accepted sources of vitamin C (the antiscorbutic vitamin), Hess demonstrated the value of tomato and potato juice in the treatment of scurvy in Negro children in New York. In this way he introduced antiscorbutic foods that were cheap and easily obtainable.

Complications arise in recommending foods as sources of particular nutritive factors because variations occur in the composition of different varieties of the same product as the result, for example, of differences in maturity, climate, and the fertility of the soil. Take, for instance, green leaves as a source of carotene, the precursor of vitamin A. Carotene is rather abundant in fresh green leaves, but as soon as they are picked the carotene begins to disappear. The loss is least under refrigeration and in an oxygen-free atmosphere. Drying helps to stop the disintegration, but even the dried leaves lose their vitamin potency in time, especially in hot weather. Carotene is destroyed in cooking, especially in the presence of oxygen. It is not enough, then, to know the carotene content of fresh leaves. It must be assumed that a considerable amount of carotene will be lost before the leaves are eaten, unless, of course, they are eaten in the garden. Even then there would be difficulties, for all leaves of the same plant are not equally good sources of carotene. The leaves of old-fashioned green garden lettuce may not be so attractive as the crisp inner leaves of a tight-heading variety, but these blanched inner leaves are not nearly so rich in carotene as those of the looser headed, darker green plant.

Fortunately, not all vitamins are as unstable as vitamin A. It is obvious, however, that a single statement of the composition of a food is not sufficient and that any analysis of a food as grown may need to be interpreted in the light of changes that may have occurred in it during the interval between harvesting and consumption.

The methods of preservation and purification used to keep foods from spoiling or losing quality or to make them more attractive often change the composition of the original food. Thus there may be a reduction in certain constituents upon drying or cooking, as in the case already discussed, or a concentration of carbohydrate such as occurs in the manufacture of white flour, refined sugar, and polished rice. These changes create special nutritional problems when products of this type form the major part of a diet. The use of polished rice is a good example. In polishing rice the outer hull and the germ, which contain vitamin B_1, are removed, leaving the inner starch-rich endosperm. People who live largely on polished rice develop the nutritional deficiency disease beriberi. This can be corrected by feeding the rice polish itself or some other source of vitamin B_1. But once polished rice has been used it is very difficult to get people to accept unpolished or brown rice, in spite of its superior nutritive value.

Sugar is an example of a manufactured purified product that introduces a nutritional problem, in this case because of its appeal to the taste. Sugar is practically pure carbohydrate and nutritionally valuable only as a source of energy. It is useful in adding variety and interest to foods, but when taken in excess it dulls the appetite and thus restricts the consumption of other necessary foods.

The use of refined products is not objectionable in itself, but it necessitates careful selection of other foods if the diet is to be adequate.

MENUS AND MEAL PLANS

A menu may be considered as a plan by which foods are combined to make a satisfactory meal. By working out a series of menus a variety of foods and an adequate diet can be assured. Menus tend to follow patterns and are part of our food habits. Through skillful planning of combinations of food, nutritive elements in which the diet was previously deficient may be added, often without upsetting an accustomed routine. A large part of the success of this method of changing food habits lies in maintaining interest in the meals from day to day. This is just as true for maintaining good dietary habits as for changing poor ones.

Although the immediate concern will be with the nutritive elements in the menu, it is important to remember that many other factors enter into the satisfaction people obtain from meals, particularly the methods of service and the surroundings in which food is eaten. Interest in food through the menu or meal plan is attained by—

(1) The use of foods attractive in themselves.
(2) Changes in methods of preparation of foods.
(3) Combining the foods in attractive prepared dishes.

In the last-mentioned case the attractive characteristics of some foods, such as meats and sugars, may be used to add interest to less attractive but necessary or useful foods such as the bland cereal grains, certain vegetables, or milk.

It is not enough to provide variety among the meals of one day. It is necessary also to prevent the monotony that follows the frequent repetition of foods or combinations of foods, or the repetition of the same foods at regular intervals. This is evident from the difficulties that arise in feeding large groups of persons, as in college dining halls, army messes, and correctional institutions, particularly when the cooking is mediocre. Poor cooking and monotonous meals have been responsible for many riots. It is a matter of record that Harvard College was almost wrecked in its early days because of monotonous and inadequate meals.

In making up a menu for dinner, a housewife who had a good knowledge of nutrition might go through a process of thinking something like this:

Soup? It's appetizing and not too filling.
Meat? Yes. No animal protein for the grown-ups so far today.
Potatoes? Yes.

Other vegetables? Broccoli, turnips, beets, or carrots? Make it broccoli and carrots—not enough vitamin A so far.

Salad? Lettuce with cottage cheese and pineapple—more carotene and more calcium.

Dessert? Cottage pudding? No; calcium is still low. Make it pumpkin pie and a cup of coffee with cream.

Now, let's see—we had grapefruit this morning, tomato juice this noon, and broccoli, carrots, butter, and salad tonight to provide sufficient vitamins C and A. The meat, bread, and cottage cheese, and the peanut-butter sandwiches this noon provide plenty of protein. The calcium may be a little low, but pumpkin pie has helped and there was skim milk in the bread. The children have had milk for breakfast and lunch, so their calcium intake is well taken care of.

The B factor? We had only white bread, but there were meat, peanut butter, cheese, and vegetables to help out.

There is plenty of iron; and by the time the family fills up on bread and butter there will be enough calories.

Most of us do not go through such an analysis as this. The chances are that we leave the planning of meals to someone else. Even the housewife may use ready-prepared menus. What training did the person who planned the meals have? How well was the planning done? If a pattern was followed, was the pattern good? Upon the housewife, dietitian, cook, or steward is often thrown the responsibility for inducing us to eat foods that are needed even though we may not like them. They are the ones who should be trained in the general facts of nutrition. We look to them to plan meals that we can enjoy with the assurance that they are adequate as well as appetizing.

While menus and meal plans are useful in attaining a good diet, they often do not provide sufficient evidence by which to judge adequacy. Often diets appear inadequate when judged by the menus but are shown to be adequate by analyses of the quantities of foods consumed. Conversely, a similar analysis of interesting menus may show an insufficient intake of important foods, especially vegetables.

PSYCHOLOGICAL FACTORS IN FOOD CHOICE

In adapting food to meals, there are complications that arise because of man's intelligence. In modern civilization, many people have gradually conditioned themselves to expect and demand a much more complicated dietary than is needed to satisfy nutritional needs. So far as people can afford these habits, they should enjoy them. Enjoyment is, however, only relative—as soon as new opportunities arise, dietary habits may become more elaborate. On the other hand, where enjoyment interferes with the acceptance of an adequate dietary, the individual is faced with the dilemma of continuing his habits or accepting something that appears to him to be less interesting and satisfying.

Man likes what he is used to, but he also likes a change. On this premise it should be possible, under circumstances in which he is faced with the need for a correction in the dietary, to condition himself to a new set of habits.

In any practical attempt to improve nutritional status, therefore, use should be made of instincts, appetites, habits, and any other devices to condition him favorably to desirable food choices. Hunger and appetite can be made valuable aids in securing the acceptance of food. Hunger, which is due to actual contractions of the stomach, stimulates the seeking of food. Appetite, on the other hand, is associated with the presence, or even the memory, of pleasant odors and flavors of food, and may occur even when the stomach is full. When hunger contractions or pangs occur, people show irritability and restlessness, even when the attention is so occupied that the contractions are not recognized. When three meals a day are eaten at regular hours, hunger contractions are seldom noticed, and when only one or two meals a day are eaten a certain amount of indifference to them may be built up. Excitement, pain, or anger inhibit hunger and may thus create resistance to new foods. Outdoor exercise, physical work, or insufficient food stimulate hunger and lower the level of discrimination, thus creating a situation favorable to the acceptance of new foods that may be utilized when there is need to modify dietary habits.

People often take food as a result of appetite rather than of hunger. Appetite stimulates the flow of digestive juices but is not essential to the digestion of food, since once in the stomach, food is equally well digested whether it was palatable or not, provided no serious or continuous emotional disturbances are involved.

Habit plays an important role in the acceptance as well as the refusal of certain foods and thus is useful in efforts to provide an adequate dietary. Habits are paradoxes. A man will eat the same breakfast year in and year out but will rebel if his dinners or suppers are the same, or even if they are repeated at weekly intervals. In New England, hot baked beans are or were traditionally necessary for Saturday suppers and cold baked beans for Sunday breakfasts. In the South boiled beans are often a customary second dish for both dinner and supper. In other parts of the country, if beans are served for two meals in succession there is likely to be trouble.

Man is not alone in clinging to habit in the face of change. Animals accustomed to a particular ration do not readily change to an unfamiliar diet. For instance, a farmer in Ohio purchased some cattle raised in North Dakota that had never been fed corn, and it took him some time to teach them to eat corn. He reports that one steer never did acquire the habit. Animals, however, show a greater willingness to consume the food presented to them than does man. They can also be taught to expect variety in their diets.

Modern psychology has shown how many of our actions, including attitudes toward food, are the result of conditioning or involuntary reactions to stimuli. Poffenberger favorably conditioned a group of students to music they did not like by playing it while they ate attractive meals. Most of us can explain an intense aversion to a particular food by its association with some painful event, or remember first discovering that we liked a new food when it was eaten on a gala occasion. Conscious use of such methods of modifying established habits or creating acceptance of desirable foods offers a valuable means of improving dietary habits.

The role of instinct in determining the choice of foods is not certain, but some interesting examples of its effect on choice are reported. An experiment with rats, conducted for the purpose of determining whether animals search for specific nutrients, indicated that the choice of a particular food was the result of a generalized search for food and that habit or conditioning played a part in its selection. Under experimental conditions, rats have been found to choose a satisfactory diet from 11 relatively pure foods, including protein, carbohydrates, fat, certain vitamin-rich foods, and minerals, and to increase the consumption of sodium chloride or calcium where additional quantities of these elements were needed. Experiments with chicks showed that certain of them consistently chose better diets than others.

Man's instinct or ability to select a satisfactory diet from among a number of foods or to modify the diet to meet changes in nutritive requirements has also been demonstrated. There is a careful report of three young children who were allowed complete freedom of choice from among a wide variety of natural foods over a long period of time. The diets selected met all their nutritive requirements and resulted in excellent growth.

But these are experimental conditions. Under the normal conditions of everyday life, man's instinct is so overlaid by conditioning that he cannot be trusted to select food with any relation to his physiological needs.

At present sufficient evidence to determine the exact manner in which the body recognizes nutritional deficiencies and determines the choice of food is lacking. One suggestion is that nutritional deficits cause physiological changes in the body and that these changes alter the taste mechanism and set up a craving for a specific food.

PROBLEMS IN TEACHING GOOD FOOD HABITS

A survey of dietary habits indicates that there is still much to be done in bringing people to choose or accept a diet that meets the energy needs of the body and provides a liberal allowance of all the nutrients required. The difficulties involved become evident when an attempt is made to change the food habits of persons satisfied with a diet that is adequate from the standpoint of energy but inadequate in other respects; to make drastic changes in the food of troops and yet maintain their morale; to attempt to set up a restricted though adequate diet for people on relief; or even to solve the problems of the housewife who is trying to stay within her food budget and still have a well-nourished and satisfied family. In each case the major difficulty lies in getting the persons concerned to accept the foods that should be used among those that are available.

The most promising solution of the problem of getting people to accept an available adequate diet lies in education and training. Training must begin with the establishment of good food habits in the child, and involves learning to enjoy a simple adequate diet and to accept new foods to replace or supplement customary foods. Success depends largely on the skill and attitudes of the mother. Although education begins at home, it should be carried on also in the schools. Information given there reaches back into the home and affects the parents and other members of the family.

Finally, there are great possibilities for general education for better dietary habits, particularly for adults. Here the problem is to insure the sound, broad presentation of facts, unbiased and in their proper relationships. Many books, bulletins, and pamphlets containing a large amount of information about nutrition are available for use in the home and school. Radio broadcasts and household publications offer advice and aid in planning meals. Many of these are biased, however, and the information should be carefully evaluated before it is accepted. Great care must be taken to make sure that material to be used in schools is factually accurate, that it presents completely unbiased discussions, and that it promotes no food product exclusively.

A considerable part of the current popular material about food is presented in the form of recipes or suggestions for new ways of utilizing foods. This kind of material is very useful in securing the acceptance of new foods or the wider use of common foods. Though recipes may be of little immediate interest to students of nutrition, they are of real value to those who must prepare and serve meals. To be most useful, material on the preparation of foods should present facts about the place of the foods in the dietary. An example of an excellent service of this kind is the mimeographed press release called The Market Basket, which the Department of Agriculture has issued weekly for a long time. It combines information on the general nutritive requirements of the family with information on seasonable foods and presents simple yet attractive methods of preparation.

As previously mentioned, material that is to be used as a guide either in teaching nutrition or in planning dietaries should suggest more than one major source of each of the important nutrients. This is especially true if the material is to be used by people in all parts of the country.

The average person can hardly expect to keep well informed about all the changes in and additions to knowledge of man's food requirements, but he should realize the extent to which his food habits play a part in determining his well-being. He should also realize that these habits are not infallible guides, and that a reasonably satisfactory diet with an abundant supply of nutrients can be achieved at different income levels if one is willing to bring an open mind to its acceptance.

Education and training are especially needed for those who are responsible for the planning of meals and the preparation and service of food. More attention needs to be paid in recipes to the preparation of simple inexpensive dishes that utilize in attractive forms the maximum of economical foods and the minimum of more expensive foods so that physiological requirements may be satisfied without lessening enjoyment.

FOOD FADS, FACTS, AND FANCIES

by Helen S. Mitchell[1]

QUACKS are with us still, and they do a thriving business. Today they use a scientific lingo that often sounds almost like the real article. Here is an exposition of the ways of the quack, the faddist, and the unscrupulous advertiser of food nostrums who prey on a gullible public.

THE MEDICAL or food quack is one of the most pernicious influences scientific nutrition has to meet. The food quack today uses many of the same devices, modernized, that the patent-medicine vendor used a generation ago. The quack of former days was so crude in his statements that the modern consumer wonders how people ever could have believed such buncombe. Even today there is plenty of flagrant chicanery, but the more scientific modern quack or the unscrupulous advertiser often couches his remarks in such technical language as to inspire false confidence.

The typical quack food lecturer or pseudo health promoter usually has poise, personality, and persuasion, which assure him of a hearing and a goodly number of converts. The letters usually found after his name may represent a fake degree given by a third-rate institution, sometimes founded for the express purpose of conferring the degree, or a bona fide degree given by a reputable institution whose professional and ethical standards he has long since forsaken. His pseudoscientific explanations of nutrition and physiology abound in quotations from authentic sources, sometimes misinterpreted but sometimes used correctly along with misleading statements to give the whole an air of authority. The insidious mixture of the true and false is always more difficult to interpret correctly than the glaringly false. The clever quack is well aware of popular interest in science and works accordingly. Of all quacks the food-fad promoter is the most prolific because he gets the biggest following and his is a profitable business. He makes converts faster than scientific knowledge can be broadcast, because the scientist is conservative and tries to be accurate, while he is quite the opposite.

Be skeptical of mail-order solicitations and cheap advertising of nutrition nostrums or disease cures. Reliable products will find a market through ethical channels. Be skeptical of extravagant claims.

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The consumer's best protection against fraudulent advertising is a fundamental knowledge of nutrition obtained from reliable sources. Bogert (*133*)[2] has aptly expressed the nutritionist's attitude toward this problem in general:

> The fact is that food fads flourish because people want them. It makes little difference to the food faddist whether the particular dietary cult he follows incorporates a few grains of truth along with the dross or not; he is attracted to this cult because it satisfies some craving to try a novel dietary, to be in fashion, to attract attention by being unusual in diet, or from the desire to *do something* about his health. He may benefit by the simpler diet, more regular living, and especially through the belief that he will be helped, but this proves nothing as to the theories on which the cult is based, and the same results might have been more painlessly attained by other means. The food faddist represents a psychological type and often drifts from one dietary cult to another; as long as we have this type of people in such large numbers, diet fads and cults will persist and will be profitable to their originators.

FOOD ADVERTISING

Legitimate and reliable advertising of food products is of real service to the public and deserves encouragement on this basis alone, aside from its necessity for successful competition in the commercial field. The intelligent consumer welcomes reliable information but should be disgusted with extravagant and untrue statements. Many false notions and misapprehensions regarding the magic health value of certain foods and the mysterious dangers in specific food combinations have been introduced or initiated by unscrupulous advertisers or propagandists.

Health testimonials are an all too common form of food advertising and are especially deceptive when given by people unqualified to express a scientific opinion. An academic title of Doctor or M. D. used in advertisements or testimonials is no assurance of their authoritative nature but is an unethical device often used by quacks and fakers. It is often implied or stated that a product is approved or recommended by physicians, health authorities, nurses, dietitians, or hospitals when this is not actually the case. Beware of extravagant testimonial endorsements and general health claims.

Some so-called educational food advertising presents pseudoscientific information on the nutritional or physiologic values of foods in an artfully misleading and insidiously deceptive manner. Exaggeration by implication that all the nutritive values reside in a single food or undue emphasis on the nutritional or physiologic values of any one food is a form of deception.

The larger and more ethical food companies today are supporting scientific research and are putting out valuable educational material that is welcomed by teachers of nutrition. But even the best of educational advertising naturally stresses the products of the company concerned. Otherwise it would not pay to advertise.

SCOPE OF NUTRITION FADS AND FRAUDS

A recent bulletin entitled "Facts, Fads, and Frauds in Nutrition" (*804*) classifies and summarizes some of the more popular fads and frauds with opinions expressed by recognized authorities concerning each. This bulletin helps the layman to answer for himself questions regarding extravagant and misleading nutritional propaganda.

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[2] Italic numbers in parentheses refer to Literature Cited, p. 1075.

VAGUE HEALTH CLAIMS

Both the Food and Drug Administration and the Committee on Foods of the American Medical Association have been emphatic in condemning the extravagant and misleading use of the terms "health foods," "healthful," and similar expressions. The same unwarranted claims made for patent medicines a few decades ago are made today by the manufacturers of "health foods." Weird concoctions of ground alfalfa or dried vegetables, inorganic salts, and flavoring are foisted on the public as panaceas for every conceivable ailment, real or imaginary.

The Committee on Foods is explicit in defining the proper use of the terms "health," "healthful," and "wholesome" (*20*):

> The term ***health food*** and equivalent claims or statements to the effect that a food gives or assures ***health*** are vague, misinformative and misleading. An adequate or complete diet and the recognized nutritional essentials established by the science of nutrition are necessary for health, but health depends on many other factors than those provided by such diet or nutritional essentials. No one food is essential for health; there are no *health foods*. Statements of well-established nutritional or physiologic values of foods are permissible.
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> The term *healthful* is frequently encountered in food advertising. As used, it commonly means that the food described corrects a possible nutritive deficiency or some abnormal condition in such a manner as actively to improve health. It incorrectly implies that the food possesses unique (or unusual) health-giving properties. The term has a popular specific *health food* significance which makes its use in advertising misinformative and misleading.
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> *Healthful* and *wholesome* by dictionary definition have almost identical meanings; the former, however, intimates an active significance, whereas, the latter signifies quality or condition. *Wholesome* indicates that a food so described is sound, clean, fit for consumption, and free of any objectionable qualities; it is appropriate for characterizing foods fulfilling these qualifications and should replace *healthful* as used in food advertising.

Vague health claims are frequently accompanied by equally vague use of the terms "balanced" or "scientifically balanced" foods. No one food is expected to be eaten alone, and no one food can insure that the diet will become balanced.

The misuse of the word "energy" is also popular along with other vague health claims. Most common foods yield chemical energy available for use by the human body. The use of this term in defining the fuel value of a food should not be confused with the popular and erroneous use signifying vitality, strength, vigor, or endurance. Some perfectly wholesome foods such as cereals have been widely advertised as perfectly balanced, health-giving, or energy-producing foods. Criticism of such advertising is not a criticism of the food as such but of the misleading statements made about it.

WEIGHT-CONTROL CLAIMS

Because the question of body weight is of general interest today, weight-reducing claims make a popular appeal. There are three types of reducing regimes which are or have been popular and should be recognized in their true light by the layman. (1) The true metabolic stimulants are the most dangerous; (2) the laxative salts and drugs are futile if not harmful; (3) the food supplements with recommended dietary regimes are usually harmless but may be fraudulent in their therapeutic claims.

The metabolic stimulants most commonly employed are some form of thyroid extract or the drug dinitrophenol. Both are dangerous in the hands of the layman, and the latter has been known to be the cause of cataract in several cases. Whether or not the ingredients of a proprietary compound are stated on the label, many people do not read labels intelligently and dangerous stimulants should not be used promiscuously in drug or food preparations.

Laxative salts and cathartic drugs are often incorporated in so-called reducing foods with accompanying claims that weight reduction may be accomplished without dietary control. The sudden weight reduction is due to loss of water in the stools, not loss of body fat, and both the water and the resulting weight will be promptly regained as soon as water is consumed. Furthermore, permanent injury to the digestive tract may result from such drastic but futile treatment.

The specific or proprietary food supplements with a recommended dietary base their entire success upon the dietary, which in some cases is quite satisfactory. The food supplement or concentrate is not essential to the reducing program outlined, but the layman is led to believe it is.

Quick aids to gaining weight are not so numerous as the reducing products but are equally futile and misleading. Unless food intake exceeds daily energy expenditure there can be no surplus for storage as body fat. This physiologic law holds for both the overweight and the underweight and should be the basis for evaluating any weight-control claims.

MINERAL AND ALKALIZING FOODS

There is something mysterious and rather intriguing about the mineral requirements of the human body. The scientist is seeking to solve some of the mysteries, but the quack claims he has solved them and proceeds to enlighten the gullible layman on the magic powers of some mineral food mixture. Some advertisers would lead the reader to believe that the average person is suffering from serious mineral deficiencies that can be made good only by the proprietary or natural food advertised. Smatterings of truth are so intermingled with falsehood as to give the claim a semblance of truth. Iron, iodine, and calcium, as well as a whole list of other minerals, are featured in such propaganda.

Acidosis is always prominent among the dangers listed as resulting from mineral deficiencies. The scare method is used in depicting the dire consequences of an "acid system" and its widespread occurrence. Actually, acidosis is a rather rare condition of the blood; it is not a common disease or symptom because the normal body has the necessary mechanism for disposing of both excess acids and excess alkalies. Money spent in treating such imaginary ailments is usually wasted. When true acidosis accompanies some other disease it is a problem for medical management.

VITAMIN THERAPY

Exploitation of vitamin foods has been more common even than mineral propaganda. Popular interest in vitamins may be partly the cause and partly the result of the extensive advertising of vitamins. The subject is nutritionally important and deserves attention from the consumer to the extent of seeing that the vitamin content of his daily diet is adequate. The use of more fruits, vegetables, and whole-grain products is to be encouraged, and the fortification of certain foods with vitamin concentrates may be desirable in the case of a vitamin that is not widely distributed in nature. A discussion of the pros and cons of legitimate vitamin fortification of foods is not in place here, but certainly the exploitation of the public with indefinite and general vitamin claims is to be discouraged. Such claims mean nothing when the specific vitamins and the quantity of each factor present are not indicated. For a more detailed discussion of legitimate vitamin claims the reader is referred to the bulletin previously mentioned (*804*).

FOOD COMBINATIONS

Several different food-combination fads have been promoted by self-styled nutrition experts and endorsed by thousands of unwary converts. There is no physiologic foundation for the belief that the various constituents in natural foods cannot be digested satisfactorily when eaten together at one meal. Rehfuss (*954*) has given us definite proof that proteins and carbohydrates are not incompatible, nor does an acid fruit interfere with the digestion of starch. Leporsky (*681*) has demonstrated that a combination of meat and vegetables may stimulate a better flow of digestive juices than either food alone. None of the dire consequences predicted as a result of eating a so-called wrong combination actually materialize in the experience of millions who boldly disregard such warnings. Persons who have tried one of these new systems of eating and who claim to have been helped thereby may unknowingly have made other drastic changes in their dietary habits. The possible benefit seemingly derived from any of these regimes may arise from the fact that the variety of foods eaten is an improvement over the previous diet—more fruits and vegetables, perhaps—rather than the eating of them in a prescribed order or combination.

For further information on the futility and unscientific nature of these food-combination fads, two humorous but reliable discussions of the subject are recommended (*684*, *982*).

Partly digested or predigested foods are also of questionable value, because the carbohydrate ingredient is the one usually concerned in such proprietary products—the very one least likely to need predigesting. Claims regarding aids to digestion or natural digestive elements are also unwarranted.

DIETARY PANACEAS FOR VARIOUS DISEASES

Indigestion frequently attributed to acid stomach is the quack advertising lingo used for a number of digestive remedies or diet systems. The stomach is normally acid—necessarily so for adequate digestion of food. There is just as likely to be too little as too much acid in certain abnormal states, but careful diagnosis and medical advice are necessary in such cases. Yet the quack who encourages self-diagnosis and medication still persists in suggesting the serious results of acid stomach and offers "anti-acid," "relief of acid stomach," and "cures for acid indigestion."

Constipation may frequently be controlled by simple self-medication and laxative foods, but no attempt will be made here to discuss the relative merits or proper use of such remedies. There are certain principles that should be understood, however, regarding the so-called laxative foods on the market. In general they fall into two classes—foods to which a cathartic drug has been added, and those that provide cellulose or some other form of bulk. The Food and Drug Administration considers phenolphthalein or any other such laxative drug as a harmful adulterant when it is used as an ingredient of a food. Constipation due to lack of bulk may yield to added roughage, but other types of constipation may be aggravated by similar treatment. Thus no food or form of cellulose can be rightly designated as a cure for constipation.

Diabetes, arthritis, kidney troubles, high blood pressure, and many other chronic diseases are listed in quack propaganda as curable by some specific food or dietary regime. False hopes of cure lead even intelligent persons into futile search for the impossible.

FOOD LEGENDS AND NOTIONS

Some harmless and amusing food legends and dietary notions have been handed down from generation to generation; others appear as neighborhood gossip. In one of the best popular food articles of recent date (*1*) the author comments:

> More food notions flourish in the United States than in any other civilized country on earth, and most of them are wrong. They thrive in the minds of the same people who talk about their operations; and like all mythology, they are a blend of fear, coincidence, and advertising.

LEGAL AND EDUCATIONAL ATTACK ON NUTRITION FADS AND MISLEADING ADVERTISING

The new Food, Drug, and Cosmetic Act passed in 1938 is not so effective in checking false and misleading advertising as could have been desired. It is more effective than the old Food and Drugs Act in the control of labeling, it authorizes factory inspection, and it provides for certain standards that will weed out some of the more fraudulent products. But it is still inadequate for prompt action against advertising of false or misleading nature.

Educational attempts to protect the public against false and misleading propaganda are successful only in part. Much of the informative material along this line is published in journals or bulletins not readily available to the layman. Popular interpretation of scientific discovery is apt to be conservative, while the pseudo scientific is promoted by the most spectacular devices. The psychological appeal of the latter is obviously stronger except to the well-informed person who is capable of reading between the lines. It therefore behooves the consumer to develop a reasonable degree of skepticism as well as sales resistance in respect to extravagantly advertised health foods and nutrition claims. This skepticism should be based upon a knowledge of fundamental facts, however, because it is all too easy for the layman to go to the opposite extreme and doubt everything he reads or hears. The Council on Foods of the American Medical Association publishes from time to time General Decisions that have been adopted for the guidance of the members and of the public, food manufacturers, and advertising agencies. These decisions are revised periodically as scientific progress warrants and are published in convenient booklet form (*20*) available to the public upon request.

THE WHITE RAT AS A CONTRIBUTOR TO SCIENCE

by M. H. Friedman[1]

A VERY considerable amount of the modern research work on nutrition has been done with white rats, though other laboratory animals have been used too. The rat, ordinarily the enemy of mankind, has been a benefactor in this field at least. The author of this article tells why it is used so extensively, and what can and what cannot be learned from observing its reactions in the laboratory.

In one sense the rat has been the object of experimentation ever since there were rats. Every man and beast has been an experimental animal—the subject of his own experimentation. An experiment is merely a trial by the practical test of doing rather than by thinking.

The thousands and thousands of years of man's experiments upon himself and upon his family have not been fruitless. Through such experiments of primitive peoples have come the knowledge of the boon of opium in relieving pain, the curative action of quinine in malaria, the value of burned sea sponge (rich in iodine) for the alleviation of goiter, and the dramatic effectiveness of a brew of pine needles in human scurvy. The market women of Corsica recognized the cause of the itch (scabies) and how to cure it, and then passed on their knowledge to the medical profession. Digitalis, the heart medicine, came from an old herb woman in Shropshire, England.

Until recently (the last 300 or 400 years) this method of learning by trial and error was practiced only by animals and by the average man. It was beneath the attention of the scholars, who were content to speculate and argue whether man possessed the same number of ribs as the animals, or one less. It did not occur to them to find out by looking.

When scholars did begin to look, the rat was not prominent among the objects of their attention. Naturally the first observations were concerned with the structure of the body—anatomy. The early anatomists were interested in finding out about the structure of the human body and the structure of the bodies of the animals they encountered in their everyday life. They seized their chances for dissection on a recently killed pig, sheep, or dog. They stealthily cut down from the gallows some thief or cutthroat. They learned that under the skin man and beast are very much alike, and that one animal very much resembles any other animal. The contents of the chest and abdomen are the same. The arrangement of the heart, lungs, and great vessels is similar. The nerves originate from the brain and spinal cord in the same fashion and follow the same general course to the same groups of muscles. From system to system, with few minor exceptions, the architecture follows the same pattern.

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On the basis of structure, therefore, there was no reason for the early investigators to favor any one species of animal over others—and they did not. The circulation of the blood was discovered by the studies of Harvey (1628) on snakes, fishes, birds, pigs, and dogs. He observed the beating heart in the developing egg of the chicken and in a prematurely expelled human fetus. An old mare permitted Rev. Stephen Hales, curate of Teddington, England, to make the first measurements of blood pressure (1710). The first secrets of the process of digestion were vomited up by the pet hawk of Réaumur, the lawyer (1752), but knowledge of digestion was greatly augmented a few years later by the labors of the Abbé Spallanzani, who enlisted the services of birds, sheep, oxen, horses, cats, and dogs, not to mention himself. An accidental gunshot wound in the abdomen of a young Canadian enabled a brilliant Army surgeon, William Beaumont, to make his fundamental contribution (1825) to the physiology of the stomach.

One of the earliest planned experiments in nutrition was performed with sailors of the English Navy as experimental animals. The results of this experiment (1776) led to the recognition of scurvy as a deficiency disease. About 100 years later a similar experiment on sailors of the Japanese Navy established beriberi as a dietary disease. For the pioneer work in metabolism (the burning and conversion of foodstuff in the body) Voit and Bischoff (1860) made their observations on dogs.

Thus, through the services of almost every animal the outlines of the story of physiology were unfolded, and through these services it became evident that all mammals (warm-blooded animals which suckle their young) conduct their life processes in essentially the same way. They all take in fuel in the form of carbohydrate, fat, and protein for the repair of their tissues and for the maintenance of a uniform body temperature. In all mammals the body temperature is about the same as it is in man, and from the mouse to the elephant, per unit of body surface, the rate of fuel combustion to maintain this temperature is almost identical. Per unit of fuel burned, the amount of oxygen required, and the amount of carbon dioxide given off in the respiratory exhaust are the same, and the respiratory mechanism which handles these gases is no different in the bat from what it is in the whale. The heart of a baboon is governed by the same impulses as that of man, quickened and slowed by the same nervous influences, and stirred in the same way and by precisely the same mechanisms in excitement, fright, pain, and anger. In the region of the Great Lakes it was not only the women who wore necklaces of excess thyroid tissues before the days of iodized salt. Female rats also had goiters, as did the dogs, cats, pigs, and even the fish in the streams and lakes.

The active substance in the thyroid gland, which is responsible for the dramatic effects on metabolism, growth, and nervous reactions is chemically the same in all warm-blooded animals, so that the material from the cow's thyroid produces its characteristic action when fed to a rat, dog, or man. In fact, from system to system—from the contractions of the bowel to the vibrations of the hearing apparatus—the fundamental processes of life are the same.

Consequently, there is usually no imperative reason why one type of animal should be used for the scientist's observations instead of another. Frequently, convenience guides the investigator in his choice. For example, most work on the movements of the digestive tract is done with dogs, for the dog is not only intelligent but is probably the most cooperative of all experimental animals. Treated with kindliness and consideration, he will quickly learn the routine of an experiment. When the investigator swallows a small balloon, he will swallow one too, and then lie quietly for hours while records are being taken of muscular movements in the stomach. He will take his place alongside of the human volunteers at every step of the experiments.

There are some instances, however, in which some unusual trait will either eliminate one species from consideration or will recommend it above all others for a particular type of work. Thus, the guinea pig is too stupid to serve in experiments in psychology. The rabbit is a poor choice for illustrating the mechanism of walking since its hind end is organized for hopping, not walking. The rat will not do for studies on the gall bladder—it has no gall bladder, though the mouse has. Neither the rat nor the mouse is able to vomit what it has once swallowed, regardless of the stimulus; hence squill, which only mildly affects a dog or cat, is deadly poison to the rat. The hawk, contrarily, habitually spews up bones, feathers, or anything else too formidable for its stomach to digest. It was this trait which enabled Réaumur to feed his pet hawk sponges with the full assurance that before long the bird would return the sponges well filled with stomach secretions for his studies.

Each species has its virtues and its failings—either of which may be a deciding factor in a particular situation. The rat possesses no long list of virtues which set it apart from all other animals. Perhaps its chief virtue is that it is not different; that in all essentials it is very much like man and any other animal, and that it is small. This question of size has become an important one in recent years. The pioneers in physiology could find answers to their questions by experiments of very short duration, a few minutes, or hours at most. Many of the questions confronting the modern investigator can be answered only by experiments that cover the entire life of the experimental animal, or even several successive generations of animals. For such long periods of observation the investigator must pay special attention to some very practical considerations, all of which are related to size.

Perhaps the first of these practical considerations is that of maintenance under laboratory conditions. This involves the question of space. Here the advantage is obviously with the smaller animal, and the smaller the better. The elephant is just as docile and gentle as the rat, is certainly as intelligent, and can be more easily trained. But it would require a national park to house an adequate experimental colony. Several hundred rats can be accommodated in comfort in a room not much larger than the ordinary living room, allowing them sufficient fresh air and room for exercise. In such quarters they thrive (fig. 1). This would be impossible with such domestic animals as the dog or cat, and even with the rabbit the space required is significantly greater.

Figure 1.—A family of white rats reared for vitamin assay work with foods in a Bureau of Home Economics laboratory.

With respect to feed also the smaller animal has the distinct advantage. On the basis of present-day prices the yearly cost for the food of one rat is under 50 cents. The annual food bill for a rabbit is about $4.50; for a dog, $15; and for a dairy cow, $75. The appetite of the elephant demands about $400 worth of food each year. These prices reflect the quantities of foodstuffs consumed and are, of course, in terms of inexpensive commercial supplies. In the event that special diets are required these differences are greatly magnified. For example, a rat eats about 10 grams of food a day (one-third of an ounce), 15 percent of this being protein. Hence, if an investigator wished to study the effects of single amino acids as substitutes for the crude protein, he would have to supply about 1.5 grams daily of a suitable mixture of amino acids. The present cost of such a mixture of amino acids is of the order of $1 per gram, so that in this experiment the cost per rat would be about $1.50 each day. For a rabbit the comparable figure would be $15 a day. Moreover such an experiment would be useless unless the remainder of the diet were composed of chemically pure, simple compounds in order to avoid contamination with traces of proteins or amino acids in the starches and fats which are required. This, of course, would boost the cost still higher. By and large, feeding experiments on the rabbit, or on any larger animal, cannot be expected to give any more information than the same experiment conducted on the rat. The cost of some of the experiments dealing with pure substances are almost prohibitive even with the rat as the experimental animal,[2] and with other animals such experiments are quite out of the realm of possibility.

Also related to the size of the animal is the amount of waste to be disposed of. With the smaller animals the problem is simple and easily met, but the cost of cleaning up after the larger animals is a limiting factor.

From the standpoint of maintenance and operating costs, therefore, it is easy to understand why the smaller animals are favored. Yet there is an even more compelling reason, and that is the fact that the larger animals live too slowly. It is no disadvantage that the horse breathes more slowly than the mouse. The investigator can afford to wait for the next breath. But it is a distinct disadvantage that the larger animals reproduce, mature, and age more slowly. For a study of the influence of diet on longevity it is obviously necessary that the investigator outlive the experimental animal. Starting at the age of 30 a young scientist might have a reasonable chance of completing one set of experiments upon cats or dogs, but he would be a reckless optimist to start such work on any of the larger animals. The odds are much better with the rat whose entire life span is only 2 to 3 years. Growth and reproduction likewise are on a fast schedule. Under laboratory conditions breeding occurs readily throughout the year. Pregnancy lasts only 21 days. At birth, the 8 to 12 young in each litter are hairless, blind, and deaf. They are as helpless as a newborn babe, but in 3 weeks they may be weaned and at the age of 6 weeks most of them are sexually mature. With such a pace of life it is not at all difficult to make observations on several successive generations of animals subjected to the experimental conditions for their entire life span.

Even with the guinea pig this is not so easily done. This dumb little beast breeds the year around, but pregnancy lasts for 65 days, there are only one or two young at a time, and they require several months to reach sexual maturity. Of all common animals the mouse is the only one able to keep pace with the rat in all respects.

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[2] In one recent investigation the amino acid requirements for maintenance and for very short periods of growth were determined on a very small number of rats. The bill for amino acids alone was over $50,000.

Why then is the rat favored instead of the mouse? It is not favored in some lines of work, as in studies on genetics. The popularity of the rat for other types of work, especially in the field of nutrition, is probably something of an accident. As was noted before, the rat was not the first choice of the earliest workers in nutrition. In fact, the first demonstration that carbohydrate, fat, protein, and minerals were insufficient for the maintenance of life (Lunin, 1881) resulted from experiments on mice, not rats. Mice also afforded the opportunity to demonstrate that the addition of small amounts of fresh milk to such a simplified diet would maintain life and permit the growth of young animals (Pekelharing, 1905). In the light of our present knowledge these two sets of experiments obviously paved the way for the discovery of the accessory food factors, later to be known as vitamins.

But these two sets of experiments were published many years apart in journals not widely read by scientific men. It so happened that F. Gowland Hopkins in England, and Osborne and Mendel, and McCollum and Davis in this country used rats for their experiments, which were all published at about the same time (1912–13) in journals with a world-wide audience. These three independent publications fortified each other in their impact upon the consciousness of the scientific world, and together they made the world aware of the existence of vitamins. It was only natural that later workers, bent on confirming and extending this epochal work, followed as closely as possible the conditions stipulated by the original investigators. The use of the rat was one of the conditions.

During the progress of the early work on vitamins, Henry H. Donaldson was already at work on his studies on the growth and development of the nervous system, and it so happened that he also chose the rat as his experimental animal. As a matter of course the growth of the nervous system was compared with the growth and development of other body parts. Data were thus secured on the size of every body organ at every stage of development, on the water content of all parts of the body at all ages, and on the chemical composition of the body as a whole and of each of its component parts from birth to old age. These data were supplemented by observations on reproduction, fertility, and development to maturity and were compared with the rapidly accumulating record in the laboratories of McCollum, Osborne and Mendel, and others, where the rat was being used for nutrition experiments.

Hence, there became available information about the white rat under laboratory conditions such as existed for no other animal. This body of data, complete with tables and graphs, was published (1915) shortly after the appearance of the epochal papers of Hopkins, McCollum and Davis, and Osborne and Mendel. Laboratories now had before them standards of performance for the albino rat, and through the courtesy of Dr. Donaldson's Wistar Institute in Philadelphia breeding stock of his standardized white rat became available to all who desired it.

Not all laboratories used this particular strain. In fact, there are now in this country four or five chief strains of laboratory rats, each having their individual characteristics as to rate of growth and development, as well as mature size. Nevertheless, the contributions of Dr. Donaldson, coming when they did, gave a tremendous impulse to the rapidly growing use of the rat.

In the intervening years the use of the rat has been extended to more and more new lines of work, and there is no reason why this should not continue. The rat has served admirably. Though other animals might serve just as well in a number of respects, no other single animal would serve better.

However, that is just the difficulty with rat experiments. No single species of animal can serve as a trial horse for all living things. The rat is, after all, a rat, and possesses its own distinct physiological individuality just as any other animal does. If we had to depend upon the rat as a sole experimental animal, vitamin C would never have been discovered. The rat gets along very well without this vitamin, being immune to scurvy. On pellagra-producing diets, rats do not thrive, but they do not develop typical pellagra. Diets sufficiently low in vitamin E to produce complete sterility in rats support normal health and reproduction in rabbits and goats. A percentage of cod-liver oil in simplified diets which promotes growth and good health in the rat may kill guinea pigs, rabbits, sheep, and goats. The rat, like man and dog, goes to sleep under morphine, but cats and horses go wild. In its response to pituitrin the rat uterus resembles that of the guinea pig and mouse, and differs from that of the rabbit. Histamine relaxes the rat uterus, but contracts the uterus of every other species. For the maintenance of pregnancy the corpora lutea (yellow bodies) of the rat are essential for the entire period of gestation, just as they are in the mouse and rabbit, yet in the guinea pig, monkey, and woman, the corpora lutea can be removed early in pregnancy without resulting in abortion.

It would be possible to recite a great many other characteristics that make for the individuality of the rat, just as it would in the case of any other animal. This is no argument against further use of the rat. Experiments on the laboratory rat may be expected to continue to yield valuable information in all fields of investigation—information likely to be duplicated by similar experiments on most other species in most instances. Yet, because of physiological individuality, we cannot determine the nutritional requirements of monkeys by experiments on rats any more than we can determine the nutritional requirements of man by experiments on monkeys. We simply cannot apply to one species of animal conclusions derived from experiments on another. We can, however, use the information obtained from rats as a guide to the general pattern of mammalian life. In most instances studies on other animals will show the reaction of the rat to be typical—that is, like that of the majority of mammals. In other instances, the reaction of the rat will be found not to be typical. For specific information about the reaction of any particular species of animal it will be necessary to make the actual trial on the species in question. The proof of the pudding is in the eating, and each animal has to eat his own pudding.

HUMAN FOOD REQUIREMENTS—CARBOHYDRATES, FATS, ENERGY

SOME of the earliest scientific work in nutrition was concerned with discovering the needs of the human body for energy: almost everyone remembers the days when nutrition was something that had to do with calories. As a result of these years of work, energy requirements have been worked out with considerable accuracy for men, women, and children of different ages and degrees of activity. Most of our energy supply is derived from carbohydrates (sugars and starches) and fats. Here is an up-to-date account of the principal facts known about this subject.

CARBOHYDRATES

by Helen S. Mitchell[1]

CARBOHYDRATES make up 50 to 60 percent, or more than half, of the American diet. They contribute the cheapest, most easily digested, and most quickly available forms of fuel and also indigestible fiber or residue. The digestible forms are the sugars and starches. The so-called indigestible carbohydrates are cellulose, hemicellulose, and related compounds. They are only slightly if at all available as fuel but may have other physiologic values, particularly in the digestive tract.[2]

The properties of the common forms of carbohydrate and their specific functions in human nutrition require further study. The present concept of the absorption and metabolism of carbohydrates in normal and in pathologic subjects presents an intricate but logical picture. Chemistry, physics, and physiology have each contributed to it, but it is still incomplete in certain details.

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[2] The carbohydrate content of foods as given in most food analyses is not determined directly but is calculated as that part of the total not accounted for by protein, fat, ash, and water, and includes both digestible and indigestible forms. There are no adequate chemical methods for determining total digestible carbohydrate, but the standard procedure for determining total fiber may be used to measure the indigestible carbohydrate, or cellulose, in plant tissues. Chemical methods for determining available carbohydrate in certain leafy vegetables have been the subject of recent studies. The figures now given for total carbohydrate in all dietetic food tables are definitely misleading, and complete and accurate figures for digestible carbohydrate in common foods are badly needed, especially in order that therapeutic diets containing limited amounts of carbohydrate may be more accurately calculated.

DIGESTIBLE CARBOHYDRATES

SUGARS

Chemically, carbohydrates are classified in common language as single sugars, double sugars, and complex sugars—technically called monosaccharides, disaccharides, and polysaccharides. A monosaccharide or single sugar is one that cannot be split chemically into two or more sugars. A disaccharide can be split chemically into two single sugars. A polysaccharide can be split chemically into more than two sugars.

The single sugars (monosaccharides) require no digestion and are readily absorbed from the intestine directly into the blood stream. Three single sugars occur in foods or are formed from other carbohydrates in the processes of digestion—glucose, fructose, and galactose.

Glucose, also called dextrose, is abundant in fruits and vegetables. It is also formed from other carbohydrates in digestion. In fact, all digestible carbohydrates must be converted to glucose or other single sugars before they can be transported by the blood or used by the tissues of the body.

Fructose (fruit sugar), also called levulose, is found associated with glucose in fruits and vegetables and in honey.

Galactose does not occur naturally in foods. When milk sugar or lactose (a disaccharide) is digested, it is broken up into galactose and glucose in the digestive tract. Galactose can be manufactured from milk sugar, and it is used for experimental and therapeutic purposes. Human tolerance for this sugar is limited by the ability of the liver to turn it into glucose. Recently it has been used by the medical profession to test the functioning of the liver. The rat apparently has a low tolerance for galactose, and when this sugar is fed to rats the galactose content of the blood rises and the eyes develop cataracts. Mineral and vitamin deficiencies do not seem to influence the metabolism of galactose, and massive doses of vitamins do not change it. A deficiency of protein, however, aggravates the injury caused by galactose, and rations high in protein show a definite protective effect. Further experimental work in feeding galactose to rats may throw more light on the metabolism of carbohydrates.

The double sugars, or disaccharides, commonly encountered in foods are sucrose (cane or beet sugar), maltose (malt sugar), and lactose (milk sugar). Each is broken down by the action of specific enzymes in the human intestine to single sugars which can be directly absorbed in the blood stream. Each of the three double sugars has distinct characteristics of interest in human nutrition.

Ordinary granulated sugar (sucrose) is one of the sweetest forms of sugar and costs the least. Consequently it is consumed in greater quantities than all others, in some instances to the detriment of health, because high concentrations of sucrose have an irritating effect on the tissues lining the alimentary tract, and also because they tend to satisfy the appetite and thus reduce the consumption of other foods.

Maltose, or malt sugar, does not occur free in nature but is manufactured from starch through the action—called malt digestion—of an enzyme present in sprouting grain. Maltose is an intermediate product in the digestion of starch and is easily utilized by the human *body. For this reason it is sometimes used in infant and invalid diets* where it is desirable to have a soluble form of carbohydrate less sweet than granulated sugar.

Milk sugar, or lactose, is more slowly digested than the other two double sugars and when consumed in amounts greater than those ordinarily present in milk some of it may not be digested. An undigested residue of lactose in the large intestine has a laxative action which may be desirable in certain instances but which in excess causes diarrhea. Lactose is an excellent medium for the growth of certain useful acid-tolerant types of bacteria and has been used therapeutically to increase this type of bacterial flora in the large intestine.

There is experimental evidence that lactose increases the absorption or availability of certain forms of calcium. This finding has frequently been cited as one explanation for the efficient utilization of calcium from milk. A therapeutic application of this principle is being made in cases of allergy to milk; lactose is prescribed as an accompaniment of the calcium salts sometimes used by those who cannot drink milk. There is, however, decided lack of information as to what effect certain calcium salts may have on the digestion and absorption of the sugars. While milk sugar might seem to be the logical form of sugar to add to milk for infant feeding, it offers no advantages over less expensive types and is not advised except where a laxative effect is desired. Corn sirup, which is practically pure glucose, is wholesome, economical, and convenient and is more commonly used in milk formulas today than any other sugar.

STARCHES, GLYCOGEN, AND DEXTRINS

Starches, glycogen, and dextrins are polysaccharides, carbohydrates of complex composition. The starches, found in grains, vegetables, and other plant products, and glycogen, found in liver, require digestion to the single-sugar stage before they can be absorbed and utilized by the human body. Cooked starch is reduced to maltose by the action of saliva, and both raw and cooked starch are reduced by the action of the pancreatic juices to maltose. An enzyme, maltase, breaks down the maltose to glucose.

Starch is the form in which carbohydrates are usually stored in plants. It is usually found in the plant encased in a cellulose wrapping, the cell wall, which is more or less resistant to digestion.

The relative digestibility of starches from different sources has been the subject of some debate and apparent misunderstanding. Starches from arrowroot, tapioca, and sago were supposed to be more easily digested than starches from such grains as corn, wheat, and rice. However, while the cooking time and the rate of salivary digestion may vary, the ultimate completeness of the utilization, known as the coefficient of digestibility, varies only slightly for starches from different sources. Moreover, the conditions under which the food is eaten have little influence and individual variation is less than generally supposed.

Glycogen is often called animal starch. It is important because it is the form in which carbohydrate is stored as fuel in the liver and muscles of the body. As food, however, it is relatively unimportant because of the small amount ordinarily consumed. The factors controlling glycogen formation and break-down in the body are the subject of much current research in connection with the metabolism of carbohydrates.

Dextrins occur as intermediate products in the process of digestion of starches in the body, in malt digestion, or in chemical break-down outside the body. They are also manufactured for various commercial purposes other than food, such as mucilages. The Government is a large user of dextrin made from cassava starch in its manufacture of postage stamps.

INDIGESTIBLE CARBOHYDRATES

CELLULOSE

Cellulose and hemicellulose, which together are known as fiber, form the framework of the vegetable world. They are the chief constituents of wood, of the stalks and leaves of all plants, and of the outer coverings of seeds. Fiber forms the more or less porous walls of plant cells in which water, starch, minerals, and other substances are stored, much as honey is held in the comb.

Fiber has little if any food value in the human body, but it is valuable for its mechanical effect in the digestive tract. It is usually considered an indigestible substance, but many individuals apparently utilize some of the more tender celluloses from green leaves and young shoots. There is no known enzyme in the human intestine that can digest cellulose, but bacterial fermentation or disintegration may play a role in dissolving the substances which bind together the cellulose fibers or particles. The degree of digestibility varies according to stage of growth and type of plant. The cellulose of tender shoots may disappear completely from the intestinal tract.

The indigestibility of cellulose is its major asset, since the undigested fiber furnishes the bulk necessary for efficient and normal peristaltic action (muscular contraction of the intestines). The addition of cellulose to the diet in the form of bran is often suggested in cases of chronic constipation due to lack of bulk. Other types of constipation, however, may be aggravated by bran, which is known to be irritating to a particularly sensitive digestive tract. Recent investigations conducted by Cowgill (*237*)[3] at Yale University and by Rose (*984*) at Columbia University have demonstrated in a convincing manner that the normal colon performs better when a reasonable amount of bulk or residue is present. Figures were derived from these studies as to the amount of cellulose, or indigestible fiber, that a normal person requires each day. One-fifth ounce has been suggested as an adequate daily allowance, to be increased or reduced according to individual requirements.

HEMICELLULOSES

Agar-agar and pectins are hemicelluloses, closely related to cellulose but of slightly different chemical structure. They have the ability to absorb many times their volume of water, when they become jells. Because of this property agar-agar from seaweed has been used therapeutically to increase bulk in the intestine to promote the formation of a soft stool.

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[3] Italic numbers in parentheses refer to Literature Cited, p. 1075.

The pectins in certain fruits and fruit seeds are responsible for the jellying property familiar in jelly making. Chemically these pectins are complex compounds of several simple sugar molecules. Commercial pectin, prepared from fruit seeds, is widely used for making jelly in the home as well as in the factory.

The therapeutic value of pectin and pectin products in the treatment of diarrheas has only recently been appreciated, although it was suggested by earlier casual observations. Scraped raw apple and apple powder have been successfully used in the treatment of infant dysentery when all other measures failed. Of all the possible factors present in apple the pectin component seems to be of chief value in the treatment of diarrheas. The effect of pectin has been attributed to its capacity for absorbing toxins or neutralizing harmful compounds produced by certain bacteria. The colloidal property—the ability to hold water in a jell formation—is increased in the presence of sugars. Thus pectin tends to remove irritants and provide the bulk which promotes normal physiologic peristalsis.

METABOLISM OF CARBOHYDRATES

The transportation, storage, mobilization, and oxidation of carbohydrate in the body and the maintenance of a constant blood-sugar level have been subjects of research for many years. The composite picture presented today of the mechanisms and control of these various stages in carbohydrate metabolism is too intricate to describe here in detail.

Recent work has been concentrated on regulation of oxidation and glycogen formation and break-down by the endocrine glands and the nerves. An excellent review of recent advances in this field is given by Himwich (*517*). It is apparent that the internal secretions from two glands, the anterior pituitary and adrenal cortex, work antagonistically to the insulin from another gland, the pancreas. The balance of all three of these endocrines, plus some additional influences from the central nervous system, is responsible for the normal control of carbohydrate metabolism. Thus diabetes may not be a simple insulin deficiency but a maladjustment of the several endocrine glands involved. Progress has also been made in the forms of insulin available for therapeutic use. The recognized value of protamine zinc insulin, which is slower acting than is the plain insulin, has led to further work on rates of action of various other insulin compounds or modifications. Studies on the administration of insulin by methods other than injection have met with some success, and it is hoped that the day may not be far distant when administration of insulin compounds by mouth may become practical.

It has long been recognized that carbohydrate is the preferred fuel for muscular work, but even slight muscular activity involves one of the most complex series of chemical reactions in the body. The exact sequence of events, the specific compounds involved, and the quick transformation of stored-up chemical energy into the active energy of work must all be satisfactorily explained by any proposed theory. The present concept of the series of chemical reactions which may take place during muscular contraction has been adequately reviewed by Needham (*836*). Even the chemical steps in the oxidation of a simple sugar to carbon dioxide and water are not thoroughly understood. Carbohydrate-phosphate compound,s the nitrogenous compound creatine occurring in muscle tissue and elsewhere, and several organic acids all play roles the precise nature of which is still an intricate puzzle challenging some of the best chemists of the day. Muscular activity is possible in the absence of oxygen, but lactic acid, which is a product of fatigue, accumulates more rapidly, and without oxygen, recovery from fatigue is impossible. Rapid breathing during and after muscular exertion is the body's response to the increased demand for oxygen.

INTERRELATIONSHIP OF CARBOHYDRATES AND OTHER NUTRIENTS

That various other nutritive elements play a part in the metabolism of carbohydrates is illustrated by the influence of protein on galactose metabolism and that of calcium salts on lactose metabolism, already mentioned. Deficiencies of thiamin (vitamin B_1) and riboflavin are associated with profound changes in carbohydrate metabolism. One worker found that the combined effect of thiamin and riboflavin was necessary for the functioning of insulin administered to a dog from which the pancreas had been removed and which was maintained on a diet free from the vitamin B complex. On the other hand, dogs have been kept alive without pancreas for over 4 years on high-calorie, high-protein, and high-vitamin diets. How these vitamins function is still a question. Other workers have found that sodium salts show beneficial effects in the treatment of diabetic children, while potassium salts increase glycosuria (excretion of sugar in the urine). These interrelationships in the metabolism of various foodstuffs are a promising field for further research.

FATS

by Jane G. Lease[4]

FAT is an important source of energy and contributes flavor and a satisfying quality to the diet not obtained from any other food constituent. Weight for weight, it has more than twice the fuel value of the other organic food groups—carbohydrate and protein. Thus the use of fat tends to decrease the amount of food required to supply caloric needs. The feeling of satisfaction associated with fat-containing foods seems to be due to the slowness of absorption of fats. Thus it seems to contribute what has been called staying power to meals.

As sources of energy, fats and carbohydrates are used in varying proportions. The amount of fat included in the diet is likely to depend to a considerable extent on individual taste and the availability of fatty foods as well as on energy requirements. It is well to bear in mind, however, that fats offer the means of increasing or decreasing the total amount of energy in the diet with the least change in the volume of food. People who are counting calories in order to get thin should reduce fat consumption first, and people who wish to put on weight should increase it.

Fat is one of the first foodstuffs to become scarce during war or famine, and some effort has been made to set a minimum requirement for use in these emergencies. Early workers put this requirement more or less arbitrarily at 20 grams a day. In the United States, the average daily consumption is about three times this amount. Fat consumption, in fact, generally increases as the expenditure for food rises, probably because of the usefulness of fats in improving the texture and flavor of foods.

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Chemically, a fat is a combination of glycerin and one or more of certain acids called fatty acids. The properties of the fat vary according to the kinds and amounts of the fatty acids it contains. There is a wide variety of fats in nature because there are many different fatty acids, but five of them—stearic, palmitic, butyric, oleic, and linoleic—are most abundantly represented in food fats, though a number of other fatty acids are present and may contribute desirable flavor and dietetic value to certain fats.

Fatty acids are called saturated when they contain all the hydrogen with which they can combine. Stearic, palmitic, and butyric are examples of saturated fatty acids. The fats formed from these fatty acids have melting points sufficiently high so that they are solid at ordinary temperatures. Oleic and linoleic are examples of unsaturated fatty acids. These will take on more hydrogen under suitable conditions. They make fats that are liquid at room temperature—that is, oils. Unsaturated fatty acids are less stable than the saturated acids.

SOME FUNCTIONS OF FAT

Recent research, especially with small animals, has shown that fat does more than serve merely as a source of calories in human nutrition. It is necessary for its own sake, performing certain functions essential to health and well-being. For one thing, it is an important carrier of vitamins. Four of the vitamins, A, D, E, and K, are soluble in fat, and some of the fats included in a good diet are important sources of these vitamins.

Again, certain types of fat are essential components of the tissue cells of the body. This has been known for some time, but it has not been easy to determine the effect of the fats in the diet on tissue structure. Recent work, especially that of Sinclair (*1061*) at the University of Rochester, has thrown considerable light on this subject, and more exact knowledge may be hoped for in the future.

One other definite function of fats is known. It was discovered several years ago that when fat was entirely absent from the diet of rats, they developed a characteristic disorder, among the symptoms of which were failure to grow and the appearance of scaly feet. That this could be prevented or cured by including in the diet certain unsaturated fatty acids—linoleic or linolenic—was shown by Burr and Burr (*175*) at the University of Minnesota. Lately it has been shown that an acid closely related to these, arachidonic acid, is more effective than either linoleic or linolenic. It may be that the latter two are simply building stones from which the body makes the arachidonic acid essential for the well-being of the cells (*1154*).

The essential, unsaturated fatty acids are not rare substances but occur in common fats used in the diet; lard, for example, is a good source of these acids, and most common food fats contain some of them. Even the hardened or so-called hydrogenated fats, which have come into common use in recent times—the hard white fats of vegetable origin used in cooking—have been shown to contain appreciable amounts of unsaturated fatty acids, although it might be expected that after hydrogenation they would no longer be unsaturated. A short study carried out by two German workers, Massatsch and Steudel (*763*), showed that in man, so far as their studies indicated, the hydrogenated fat was utilized as well as natural fat when substituted for it in the diet for 3 days. There is little basis, however, for claims sometimes made that hydrogenated fat is better in human nutrition or is more easily digested than natural fats. It was shown by Langworthy (*660*) that completeness of digestion is practically the same for all fats with melting points below body temperature.

In general, then, it may be considered that our needs for the essential unsaturated fatty acids are met in an ordinary diet and under normal conditions, and that we do not need to be concerned with the possibility of a lack of them.

RECENT STUDIES ON FAT RELATIONSHIPS

Several recent experiments suggest that the role of fat in relation to other constituents of the diet may prove to be very important. Mellanby (*778*) in England first focused attention on the production of rickets by a diet high in cereals and low in calcium. He attributed an "anticalcifying" action to the cereals—something that prevented the proper use of calcium in the body—because as they were increased in proportion to other elements in the diet, the severity of the rickets increased. His findings have not been universally confirmed and the argument has gone on intermittently for several years, especially as to whether the calcium and phosphorus furnished by the experimental diets were in forms available for use by the body. McDougall (*727*) has shown that the inclusion of 11 percent of fat in a high-cereal, rickets-producing diet would prevent the development of rickets. She believes the fat promotes the absorption of calcium from the intestine, on the theory that the fatty acids combine with calcium to form calcium soaps, which are readily absorbed. In the absence of fat, the calcium unites with phytin—an organic phosphoric-acid compound—to form an insoluble salt. The calcium is then not available to the body, and rickets results.

The relationship between the requirement for vitamin B_1 and the amount of fat in the diet has been the subject of much experimentation and discussion. Some workers have found fat to have a definite vitamin B_1-sparing action— that is, in the presence of fat, less vitamin B_1 is needed—whereas others have been unable to note any such action. Salmon and Goodman (*1001*) have ascertained which fats and which fatty acid esters have the greatest action in sparing vitamin B_1. Testing a number of fats, they found coconut fat to exert the greatest sparing action, whereas among the esters, the eight-carbon acid ester was the most efficacious. This is not to say that fat can replace vitamin B_1 in the diet, but apparently it is able to modify the body's need for it. With the many new methods recently available for the determination of vitamin B_1, we may hope to learn more about the relationship of fats to it.

Schantz, Elvehjem, and Hart (*1013*) found that they were able to sustain rats on a diet of whole milk to which minerals were added, but that when skim milk was used instead of whole milk considerable galactose, a form of sugar, appeared in the urine. When fat was supplied in the form of butter or several other fats, or when certain fatty acids were used, this loss was prevented. Just what role fat plays in the metabolism of the sugars lactose and galactose is still in question.

Some workers have found an increased utilization of carotene by rats when it is administered in fat as compared to administration in the form of nonfatty vegetable tissue (*616*); and workers in India (*1234*) found less excretion of carotene by human beings when fat was present in the diet than in its absence.

Active work is at present going on to establish the role played by certain fats and fatty acids in curing a severe skin trouble—a dermatitis or acrodynia (*937*, *1000*). The question is still open as to whether the lack of these fats is the sole cause of this condition or whether some member of the vitamin B_2 complex, especially vitamin B_6, is concerned. The nature of the relationship of fat to many of these situations is in doubt; fat may play a different part in each case, or the reactions noted may represent variations of the same function, other phases of which may be found as studies progress. It is certain that fat must be regarded as entering actively into and being essential for many metabolic processes.

In view of a possible correlation between the scaly condition of the skin of the rat when the essential fatty acids are lacking in the diet and eczema in children, of which the exact cause has long been a baffling problem, the fats of the blood of normal and of eczematous children were studied. Brown and Hansen (*161*) found that in certain eczematous children the amount of unsaturated fatty acids in the blood was reduced as compared with that in the blood of normal children. Furthermore, when the eczema was cured by administration of oils rich in the unsaturated fatty acids, the amount of these acids in the blood was increased. Other workers have disputed some of these findings and the work is too recent to be taken without qualifications, but it is of interest as an indication of the importance of dietary fat, which may be elaborated upon in the future.

ENERGY REQUIREMENTS

by Nancy B. Morey [5]

THE BODY needs fuel to supply energy for the work of the internal organs and the maintenance of body heat, which is a byproduct of this internal work. Work and play, which might be called external activities, also require energy. In both cases the energy must come from the burning, or oxidation, of proteins, fats, and carbohydrates, which occurs in metabolism. Since no known vitamin or salt has been found to increase muscular efficiency, it is impossible to substitute quality for quantity in the matter of calories. It takes about the same number of calories for a foot-pound of work no matter what kind of food provides them (*973*).

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[5] Nancy B. Morey was formerly Assistant in Home Economics, Cornell University.

There is a difference, however, in the number of calories in a given amount of different kinds of foods. Fats are the most concentrated body fuels, supplying more than twice as many calories as an equal weight of proteins or carbohydrates. Carbohydrates and fats are completely oxidized when digested and absorbed by the body, but proteins are not; energy-bearing residues, or metabolic products, of protein are lost, chiefly in the urine but to some extent in the feces. When a mixed diet is eaten, some fat, carbohydrate, and protein also escape digestion, so that when all possible losses are considered, the energy values to the body, or the physiological fuel values, of 1 gram each of protein, of fat, and of carbohydrate become 4, 9, and 4 calories, respectively.[6]

TABLE 1.—*Average weight according to height and age*[1]

MEN

Height (with shoes on)		Weight at age—								
		15 to 19 years	20 to 24 years	25 to 29 years	30 to 34 years	35 to 39 years	40 to 44 years	45 to 49 years	50 to 54 years	55 to 59 years
Feet	*Inches*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
5	0	110	119	124	127	129	132	134	135	136
5	1	113	121	126	129	131	134	136	137	138
5	2	116	124	128	131	133	136	138	139	140
5	3	120	127	131	134	136	139	141	142	143
5	4	124	131	134	137	140	142	144	145	146
5	5	128	135	138	141	144	146	148	149	150
5	6	132	139	142	145	148	150	152	153	154
5	7	136	142	146	149	152	154	156	157	158
5	8	140	146	150	154	157	159	161	162	163
5	9	144	150	154	158	162	164	166	167	168
5	10	148	154	158	163	167	169	171	172	173
5	11	153	158	163	168	172	175	177	178	179
6	0	158	163	169	174	178	181	183	184	185
6	1	163	168	175	180	184	187	190	191	192
6	2	168	173	181	186	191	194	197	198	199
WOMEN										
4	11	107	113	116	119	122	126	129	131	132
5	0	109	115	118	121	124	128	131	133	134
5	1	112	117	120	123	126	130	133	135	137
5	2	115	120	122	125	129	133	136	138	140
5	3	118	123	125	128	132	136	139	141	143
5	4	121	126	129	132	136	139	142	144	146
5	5	124	129	132	136	140	143	146	148	150
5	6	128	133	136	140	144	147	151	152	153
5	7	132	137	140	144	148	151	155	157	158
5	8	136	141	144	148	152	155	159	162	163
5	9	140	145	148	152	156	159	163	166	167
5	10	144	149	152	155	159	162	166	170	173
5	11	148	153	155	158	162	166	170	174	177
6	0	152	157	159	162	165	169	173	177	182

[1] Based on a study of more than 200,000 insured men and 130,000 insured women. Weights given include ordinary clothing.

The vigorous individual of normal weight may depend upon appetite to ensure the intake of the needed amount of calories if there is no scarcity of food. However, as people grow older and less active they often fail to change their habits of energy consumption, with the result that they store the extra calories and grow fatter. It has been found by the Life Extension Institute that for best health men and women above 30 years of age should try to maintain the average weight for persons of their height at 30 years, as given in table 1 (*785*). The average American woman below 30 years of age is at present inclined to be too thin; it has been found that, up to the age of 30, the healthiest women are those who are somewhat above the average weight for women of their height.

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[6] These are Atwater's fuel-value factors (see p. 169).

DETERMINING ENERGY REQUIREMENTS

By and large, the number of calories consumed by normal healthy individuals is a fairly good guide to their energy needs, and this fact is the basis of one of the chief sources of information as to energy requirements, the dietary study. Energy requirements of human beings have been studied in two ways: (1) From the point of view of energy intake, or number of calories furnished by the food habitually consumed to supply the energy for daily living; (2) from the point of view of energy output, or the amount of energy expended by the body in carrying on the various processes which make up the demand for energy.

Information on intake of calories has been furnished by dietary studies, in which the energy supply per day is calculated from a record of the kinds and amounts of foods consumed by an individual or a group over a given period. The question of energy output has been answered by calorimetry experiments, which give accurate figures for energy expenditures under specific conditions. There are various kinds of calorimeters, some more elaborate than others. The one used for the most elaborate experiments is an airtight, double-walled box, chamber, or small room, large enough for the subject to carry on various activities in comfort, with rather complex mechanisms for changing the air, preventing loss of heat in any way, and measuring all the heat given off by the subject. In the larger calorimeters a subject can live for days, receiving service through an opening with a tight cap at each end. A simple respiration apparatus can also be used for measuring energy output indirectly. In this case, the subject breathes through a mouthpiece or nosepiece and the energy output is calculated from the amount of oxygen used and other factors.

From calorimeter experiments it has been learned that the energy expended in simply maintaining the processes of life is fairly constant for the same individual from day to day and is very nearly the same for persons of the same size, age, and sex. Such a measurement is obtained by determining the hourly expenditure of energy in an individual lying awake and relaxed, at a comfortable temperature, 12 to 14 hours after his last meal, and is known as the basal metabolic rate.

VARIATIONS IN REQUIREMENTS

An individual at about the end of his first year of life has the highest energy expenditure per unit of weight that he will ever have. After the first year the basal metabolism falls gradually except for a slight rise before puberty. During young adulthood it remains fairly constant at about 1 calorie per kilogram (2.2 pounds) of body weight per hour, but falls again with old age. In general women have a slightly lower rate than do men of the same size, probably because of the larger proportion of fat in the woman's body. Basal metabolism is thought to be related to the amount of active cell tissue in the body. Some workers point out that the basal metabolism is more closely related to surface area than to weight, but in either case the same general tendencies are observed.

Low temperature (cold) increases metabolism. The taking of food also raises energy output, roughly 6 percent. Proteins increase metabolism more than do fats and carbohydrates; this is the reason for avoiding large quantities of protein-rich foods, such as meat, in hot weather. More than anything else, muscular activity increases energy expenditure. Every movement that is made means an energy expenditure over and above the basal requirement. Sitting up, standing, walking, running—each calls for a progressively greater output of energy. The energy required for all sorts of activities has been measured by many different investigators. From such figures as those in table 2 (*983*) it is possible to estimate the daily energy requirement if the approximate time spent in various activities is known.

TABLE 2.—*Energy output per kilogram (2.2 pounds) of body weight per hour for different activities* [1]

Activities incidental to everyday living	Energy output	Activities involved in housekeeping	Energy output	Activities involved in various trades	Energy output	Activities involved in recreation	Energy output
	Calories		*Calories*		*Calories*		*Calories*
Basal needs	1.0	Sewing, hand	0.4	Bookbinding	0.8	Reading aloud	0.4
Sitting quietly	.4	Sewing, machine	.4–.6	Tailoring	.9	Singing	.8
Eating	.4	Knitting	.7	Typing rapidly	1.0	Playing the piano	8–2.0
Writing	.4	Paring potatoes	.6	Shoemaking	1.0	Bicycling	2.5
Standing relaxed	.5	Dishwashing	1.0	Painting	1.3	Dancing	3.0–3.8
Dressing	.7	Ironing	1.0	Carpentry	2.3	Skating	3.5
Driving automobile	.9	Laundering	1.3	Stone masonry	4.7	Ping-pong	4.4
Walking (3 miles per hour)	2.0	Sweeping with broom	1.4	Sawing wood	5.7	Swimming	7.9
Running	7.0	Vacuum cleaning	2.7				
Going downstairs	4.1						
Going upstairs	14.7						

[1] Add 6 percent to the estimated requirement to allow for the effect of food.

From such figures and from weekly records of the time spent in the various activities of homemaking by farm women, it has been calculated that the average farmer's wife requires about 2,600 calories a day. If her weight is about 136 pounds, or 62 kilograms, which was the average weight of a group of farm women observed in New York State, the requirement per day amounts to about 42 calories per kilogram, or about 19 calories per pound. This amount agrees with the results of the few dietary studies of farm women that are available.

While many studies have been made of the energy intake of the farm family as a whole, few have measured the intake of each member individually. For the active farmer, such evidence as there is suggests a requirement of 3,500–4,000 calories a day.

Concerning the requirements of city housewives, the writer has stated elsewhere (*812*) that it appears to be true that the energy requirement of farm women is greater than that of housewives in towns and cities. Unpublished data of the Bureau of Home Economics, United States Department of Agriculture, show the time spent by 692 town and city housewives (college graduates) in different activities. In estimating the energy requirement, an average weight of 129 pounds (58.5 kilograms) was used for these women. If their average daily energy expenditure is calculated in the same way that the energy expenditure of farm women was calculated, it indicates a requirement of about 2,300 calories.

Orr and Leitch (*878*) estimate that—

> men in employment, making only a modest allowance for non-industrial activities, require daily from about 3,000 calories for the clerk and tailor to about 4,700 calories for the smith and coal miner.
>
> Women require daily not less than 2,200 calories for the housewife and typist and up to probably 3,300 calories for those engaged in heavy industrial work. The nursing mother requires from 2,900 to 3,500 calories daily.
>
> The requirements of adults will be increased by from 300 to over 1,000 calories daily by only 2 hours of sport or physical training.

Children, in addition to the requirements for maintenance and activity, need an extra supply of calories for storage in new body material as they grow. It has been calculated that about 75 surplus calories a day are required to increase the body weight 2 pounds a year. The most reliable information as to children's total energy needs has come from dietary studies, for it is difficult to confine the activities of childhood in the space necessary for calorimetry studies, or to test them by the apparatus required. While the dietary may not represent the optimum or ideal in a given case, it may be assumed that the supply of calories is sufficient if the child is of normal weight and showing normal growth.

In 1932 the results of all the available dietary studies which had ever been made of individual children were summarized by Lydia Roberts for the White House Conference on Child Health and Protection (*973*). Studies from eight different countries were included, covering a period of 50 years, 1882–1932. Many of the recent investigations were made by Roberts and her coworkers (*1177*). The results of these studies have been summarized in table 3 (*983*).

Table 3.—*Daily calorie requirements of children in terms of age and body weight*

Age (years)	Calories per kilogram for—		Calories per pound for—	
	Boys	Girls	Boys	Girls
1–2	100–90	100–90	45–40	45–40
3–5	90–80	90–80	40–36	40–36
6–9	80–70	80–70	36–32	36–32
10–13	70–60	70–60	32–27	32–27
14–15	60–55	50–45	27–25	23–20
16–17	60–55	45–40	27–25	20–18
18–19	55–50	40–35	25–23	18–16

The energy requirements of underweight children should be calculated on the basis of normal weight for children of their age and height. Figures showing normal weights of children of different heights and ages, compiled by Baldwin and Wood (*58*) and accepted by the medical profession as being correct, are given in table 4.

TABLE 4.—*Baldwin-Wood normal heights and weights for girls and boys 5 to 18 years of age*[1]

GIRLS

Height		Age													
		5 years	6 years	7 years	8 years	9 years	10 years	11 years	12 years	13 years	14 years	15 years	16 years	17 years	18 years
Feet	*Inches*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
3	2	33	33												
3	3	34	34												
3	4	36	36	36											
3	5	37	37	37											
3	6	39	39	39											
3	7	41	41	41	41										
3	8	42	42	42	42										
3	9	45	45	45	45	45									
3	10	47	47	47	48	48									
3	11	49	50	50	50	50	50								
4	0		52	52	52	52	53	53							
4	1		54	54	55	55	56	56							
4	2		56	56	57	58	59	61	62						
4	3			59	60	61	61	63	65						
4	4			63	64	64	64	65	67						
4	5			66	67	67	68	68	69	71					
4	6				69	70	70	71	71	73					
4	7				72	74	74	74	75	77	78				
4	8					76	78	78	79	81	83				
4	9					80	82	82	82	84	88	92			
4	10						84	86	86	88	93	96	101		
4	11						87	90	90	92	96	100	103	104	
5	0						91	95	95	97	101	105	108	109	111
5	1							99	100	101	105	108	112	113	116
5	2							104	105	106	109	113	115	117	118
5	3								110	110	112	116	117	119	120
5	4								114	115	117	119	120	122	123
5	5								118	120	121	122	123	125	126
5	6									124	124	125	128	129	130
5	7									128	130	131	133	133	135
5	8									131	133	135	136	138	138
5	9										135	137	138	140	142
5	10										136	138	140	142	144
5	11										138	140	142	144	145

BOYS

Height		Age													
		5 years	6 years	7 years	8 years	9 years	10 years	11 years	12 years	13 years	14 years	15 years	16 years	17 years	18 years
Feet	*Inches*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
3	2	34	34												
3	3	35	35												
3	4	36	36												
3	5	38	38	38											
3	6	39	39	39	39										
3	7	41	41	41	41										
3	8	44	44	44	44										
3	9	46	46	46	46	46									
3	10	47	48	48	48	48									
3	11	49	50	50	50	50	50								
4	0		52	53	53	53	53								
4	1		55	55	55	55	55	55							
4	2		57	58	58	58	58	58	58						
4	3			61	61	61	61	61	61						
4	4			63	64	64	64	64	64	64					
4	5			66	67	67	67	67	68	68					
4	6				70	70	70	70	71	71	72				
4	7				72	72	73	73	74	74	74				
4	8				75	76	77	77	77	78	78	80			
4	9					79	80	81	81	82	83	83			
4	10					83	84	84	85	85	86	87			
4	11						87	88	89	89	90	90	90		
5	0						91	92	92	93	94	95	96		
5	1							95	96	97	99	100	103	106	
5	2							100	101	102	103	104	107	111	116
5	3							105	106	107	108	110	113	118	123
5	4								109	111	113	115	117	121	126
5	5								114	117	118	120	122	127	131
5	6									119	122	125	128	132	136
5	7									124	128	130	134	136	139
5	8										134	134	137	141	143
5	9										137	139	144	146	149
5	10										143	144	146	148	151
5	11										148	150	151	152	154
6	0											153	155	156	158
6	1											157	160	162	164
6	2											160	164	168	170

[1] Weights are inclusive of regular clothing, except shoes, coats, and sweaters.

Height-weight averages for boys and girls up to 5 years of age (*904*) are presented in table 5 to meet a need long felt by many child specialists who have found most charts of growth norms for young children unsatisfactory on two counts. In the first place, norms such as those of Woodbury (*1253*) and of Baldwin and Baldwin and Wood (*57*, *58*) have appeared to be too low for children reared with optimal (or at least above the average for the population) medical and home care. In the second place, for such children there have been lacking adequate normal weight figures for varying heights at given months of age through the first 5 years of life.

TABLE 5.—*Height-weight averages for boys and girls 1 to 60 months of age*

Age (months)	Boys		Girls		Age (months)	Boys		Girls	
	Height	Weight	Height	Weight		Height	Weight	Height	Weight
	Inches	*Pounds*	*Inches*	*Pounds*		*Inches*	*Pounds*	*Inches*	*Pounds*
1	21.6	9.3	21.3	8.9	12	30.1	22.8	29.4	21.8
2	22.9	11.4	22.5	10.9	15	31.3	24.4	30.6	23.4
3	24.2	13.4	23.7	12.7	18	32.4	25.9	31.8	24.7
4	25.4	15.2	24.7	14.2	21	33.5	27.4	32.9	26.0
5	26.2	16.8	25.5	15.6	24	34.5	28.8	34.0	27.2
6	27.0	18.0	26.2	16.8	30	36.3	31.4	35.8	29.5
7	27.6	19.0	26.8	17.8	36	38.0	33.7	37.4	31.8
8	28.1	19.9	27.4	18.8	42	39.6	36.0	39.0	34.1
9	28.7	20.7	28.0	19.7	48	41.1	38.0	40.5	36.4
10	29.2	21.5	28.5	20.5	54	42.5	39.8	42.0	38.7
11	29.7	22.1	29.0	21.2	60	43.9	41.7	43.4	40.8

ESTABLISHING STANDARDS[7]

As knowledge of energy intake and output under various conditions has gradually accumulated, standards of energy requirements for persons of different ages and occupations have been set up and from time to time revised and extended until today there is a confusing number of such standards from which to choose.

Besides all the American standards many have been proposed in other countries. In an attempt to bring some order out of the chaos, the Health Organisation of the League of Nations called a meeting of nutrition workers in Rome in 1932. A tentative scale and standard was proposed there (*668*) which in comparison with most of the American standards seemed alarmingly low. At a more recent meeting of the League's Technical Commission on Nutrition in London, in 1935, it was pointed out (*669*) that part of the difficulty in reaching agreement was due to the fact that standards were designed for different purposes, some to represent minimum requirements, others optimum needs. While this is perhaps less true of energy requirements than of other dietary essentials, it may explain the low standards adopted at the first conference.

At the London meeting, the commission adopted a scale and standards expressed quite differently from all others:

> Instead of adopting a mean [average] figure representing the needs of an adult man performing an average but indeterminate output of work, the Committee

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[7] The discussion in the following pages is somewhat more technical in character and is intended primarily for students of nutrition and professional workers.

> fixed a basic figure representing the requirement for maintenance to which supplements could be added for work, growth, pregnancy and lactation. This basic [maintenance] figure represents the need of the average adult male or female living an ordinary everyday life in a temperate climate and not engaged in manual work. The [maintenance] needs of such an individual are stated to be met by 2,400 calories net (after deducting waste in cooking and at table) per day (*671*).

This, it was pointed out, amounts to about 100 calories per hour. No distinction was made between the sexes for individuals of approximately the same height and weight and in the same age group. As the amount of muscular work varies with occupation and number of hours, it was suggested that supplements be calculated on an hourly basis for the type of work done:

> The following supplements for muscular activity should be added to the basic requirements:
> Light work: up to 75 calories per hour of work.
> Moderate: 75 to 150 calories per hour of work.
> Hard work: 150 to 300 calories per hour of work.
> Very hard work: 300 calories and upwards per hour of work.
>
> The muscular activities characteristic of every healthy child and adolescent necessitate additions to their basic requirements. [See table 6.] It is suggested that the activities of children of both sexes from 5 to 11 years be considered equivalent to light work, of boys from 11 to 15 years as moderate work, and of girls from 11 to 15 upwards as light work.

According to the commission's report, the requirements of women in pregnancy are to be calculated in the same way as their normal requirements, but a nursing woman is given a basic allowance of 1.25 times the normal requirement, or a total of 3,000 calories, to which additional allowances for activity are to be made.

Babies up to 6 months of age require 100 calories per kilogram of weight or 45.4 calories a pound a day; at 6 to 12 months, 90 calories a kilogram, or 40.9 calories a pound.

Table 6.—*Proportion of adult basic requirement and basic number of calories per day for children 1 to 12 years of age*

Age (years)	Coefficient	Calories	Age (years)	Coefficient	Calories	Age (years)	Coefficient	Calories
1 to 2	0.35	840	5 to 7	0.60	1,440	11 to 12	0.90	2,160
2 to 3	.42	1,000	7 to 9	.70	1,680	12 and over	1.00	2,400
3 to 5	.50	1,200	9 to 11	.80	1,920			

In discussing these figures in its 1937 meeting, the Technical Commission states (*670*)—

> it is obvious that the appraisal of the muscular activity of a given individual, as well as of the energy supplements involved, is but approximate at best. It is impossible to suggest a single set of figures which are internationally applicable, since the energy requirements of men, of women and of children of different ages differ greatly from country to country, and even within one and the same country, owing to such factors as differences in the length of the working day, differences in the intensity of activity, in average body size, in climate, etc. Therefore the Commission makes no attempt to suggest single figures for the total energy requirements of each category of individuals.
>
> Since, however, such figures are needed in connection with dietary surveys for constructing scales of relative requirements, the energy supplements required in addition to the basic allowances should be noted by the nutrition experts responsi-

ble for the dietary surveys. When the total energy requirements have thus been determined, scales of relative requirements can easily be developed, using as unity either 2,400 calories, the allowance for a sedentary man, or 3,000 calories, the allowance for a moderately active man.

The following schedule may be of use in drawing up such scales. Column 1 contains the Commission's allowances for energy requirements in average basic diets. Columns 2 and 3 provide space for the investigator's entry of the average number of hours during which the subjects are especially active, and the average number of calories per hour needed to support this activity. In column 4 can be entered the total daily allowances. In column 5 or 6, the totals given in column 4 should be expressed as decimal fractions of the two values of unity—i. e., 2,400 or 3,000 calories, respectively.

The decimal coefficient which is to be given in one of these two columns expresses the relation of the total ration (column 4) to the value of unity chosen.

Scales based on either value of unity may be used in appraising the calorie value of diets, provided that the value of unity and the scale used are stated along with the results.

Schedules for recording Relative Energy Allowances

Individual	Energy allowance for basic diets (without work) in net calories	Supplementary allowance for special activity		Total energy allowance in net calories [1]	Scale of relative allowances [2]	
		No. of hours of special activity	No. of calories per hour of activity		Total, 2,400 =1.00	Total, 3,000 =1.00
	1	2	3	4	5	6
Men (20 to 59 years):						
Sedentary	2,400					
Light work	2,400					
Moderate work	2,400					
Hard work	2,400					
Very hard work	2,400					
60 years and over	2,400					
Women:						
Ordinary life	2,400					
Housework	2,400					
Pregnant + housework	2,400					
Nursing + housework	3,000					
Boys:						
Between 15 and 19 years	2,400					
" 12 " 15 "	2,400					
" 11 " 12 "	2,160					
" 9 " 11 "	1,920					
" 7 " 9 "	1,680					
" 5 " 7 "	1,440					
Girls:						
Between 15 and 19 years	2,400					
" 12 " 15 "	2,400					
" 11 " 12 "	2,160					
" 9 " 11 "	1,920					
" 7 " 9 "	1,680					
" 5 " 7 "	1,440					
Children:						
Between 3 and 5 years	1,200					
" 2 " 3 "	1,000					
" 1 " 2 "	840					
Under 1 year [3]						

[1] Computed to nearest 100.
[2] Computed to nearest 0.05.
[3] To be computed on basis of weight.

In order to illustrate the way in which the scales should be computed, the Commission cites the following arbitrary example:

Individual	Energy allowance for basic diets (without work) in net calories	Supplementary allowance for special activity		Total energy allowance in net calories[1]	Scale of relative allowances[2]	
		No. of hours of special activity	No. of calories per hour of activity		Total, 2,400 =1.00	Total, 3,000 =1.00
	1	2	3	4	5	6
Man, weighing about 70 kg., aged 20 to 59 years:						
Sedentary	2, 400	0	----------	2, 400	1. 00	0. 80
Light work	2, 400	8	35	2, 700	1. 15	. 90
Moderate work	2, 400	8	75	3, 000	1. 25	1. 00
Hard work	2, 400	8	150	3, 600	1. 50	1. 20
Very hard work	2. 400	7	300	4. 500	1. 90	1. 50

[1] Computed to nearest 100.
[2] Computed to nearest 0.05.

Here, then, are standards and scales summing up present-day knowledge of energy requirements and agreed upon by nutrition experts from Austria, France, Great Britain, Italy, the Scandinavian countries, the Union of Soviet Socialist Republics, and the United States. The commission hopes that future studies will be based on these scales and standards, facilitating comparisons of studies made in different countries; but most of all, it hopes that all nations will provide for their citizens the full benefits of adequate nutrition as summed up in these standards.

A BRIEF HISTORY OF THE DEVELOPMENT OF FOOD-ENERGY STANDARDS

Fuel-value factors—the respective energy-producing values of 1 gram of protein, of fat, and of carbohydrate—were first determined by the German physiologist, Rubner, in 1884 (*991*). His factors—4.1, 9.3, 4.1– took into account only those losses due to incomplete oxidation of protein and were therefore slightly higher than those determined by Atwater in 1899, which allowed for all possible losses (p. 161). Rubner's factors are most widely used in other countries, Atwater's in this country.

The first energy standards were based to a large extent upon dietary studies which had already been made by the great German scientist, Carl Voit, and students in his laboratory before Rubner determined the fuel-value factors. The results of some of these studies, stated in terms of the number of grams each of protein, fat, and carbohydrate contained in the diets, had been suggested by Voit in 1881 as standard requirements for persons of the ages and activities represented. Rubner's work of determining the fuel-value factors, which was carried out in Voit's laboratory and at Voit's suggestion, made it possible to calculate the energy values of the standard diets. The energy allowances were found to be 3,055 calories per day for a man at "moderately hard work," 2,426 calories for a woman at ordinary work about the house, 2,041 calories for children 15 down to 6 years of age, and 767 calories for children under 2 years (*47*). The small amount of data on children at that time is indicated by the wide age grouping and the lack of data for ages between 2 and 6 years.

Soon after the publication of Rubner's energy factors, an investigation was begun in the United States to determine the dietary habits and energy requirements of laborers. This work was started by W. O. Atwater, director of the first agricultural experiment station established in this country, at Storrs, Conn. Later, as first director of the Office of Experiment Stations in the United States Department of Agriculture, he encouraged the experiment stations throughout the United States to undertake dietary studies. These studies initiated by Atwater became the most extensive series of investigations of the kind ever made. Not only did Atwater promote the widespread study of American dietaries, but he was also responsible for the building of the most technically perfect calorimeter ever devised for the measurement of human energy expenditure. Many invaluable experiments were carried out in this calorimeter. Atwater always insisted that investigations into human nutrition should go hand in hand with the study of problems of scientific farming; he considered the proper nourishment of human beings a logical part of those problems.

Atwater was the first to express energy requirements in terms of a scale of coefficients, the unit of which was the energy need of an average man at moderately active work. His purpose in expressing energy requirements in this way was to make possible the comparison of the energy intake of families or groups of persons varying in age and activity, for it is much more practicable to measure the quantities of foods consumed by a family or group than to measure the amounts eaten by each individual in the group. Atwater stated the problem thus:

> If . . . we could take a particular class, as laboring men at moderate work, and find to how many average men of this class the people nourished by each dietary would be equivalent in their demands for nutrients, we should simply have to divide the total quantity of nutrients supplied per day by this equivalent number of men to get the quantities per man per day (*47*).

As his unit Atwater took the standard proposed by Voit from studies of the food consumption of German laborers, 3,055 calories. He expressed Voit's standards for women and children as fractions of this amount: Man at moderate work, 1.0; woman at ordinary work about the house, 0.8; child 15 to 6 years, 0.7; child 6 to 2 years (this he interpolated from Voit's figures), 0.5; child under 2 years, 0.25.

Atwater was astonished to find that the energy values of the diets of American workmen were higher than those of German workers, and he came to the conclusion that American workers had "the liberal nourishment . . . essential to large production, high wages, and the highest physical existence" (*48, p. 190*). On the basis of his studies he proposed 3,500 calories a day as the standard energy requirement for American workmen. The inadequacy of the energy scale as concerns children need not raise doubts as to the accuracy of Atwater's figures for laborers, for the studies upon which these conclusions were based were carried out at factory workers' boarding houses and included large numbers of workers with few or no women or children. The energy values of these first studies were calculated by the use of Rubner's energy factors; on the basis of Atwater's own factors, worked out later, the standard became 3,400 calories (*49*).

The fact that the change in standard from 3,055 to 3,500 calories automatically raised the allowances made for women and children by the original energy scale was never pointed out. This was probably because the dietary scales were not used to estimate the needs of families or groups at that time, but only to reduce them to a common unit for purposes of comparison. For this purpose the standard upon which the scale is based is not so important as that the same scale be used always to measure the man-units in the groups to be compared. When a scale is used to estimate the needs of a family, a group, or a nation, the standard becomes very important and accuracy in the scale is desired. In 1897 it was first suggested that the scale might be used to estimate needs (*50*), and in later years this became the chief use of dietary scales.

Atwater's scale was often enlarged to take account of varying degrees of adult activity as studies of persons engaged in different occupations were made. The scale was also revised to take account of the requirements of children at closer age intervals. Although few dietary studies of American children were made in Atwater's time, data were available from the increasing numbers of studies of German children. Many standards and scales have since been proposed both in this country and in other countries. Most of them have been based on an "adult male unit" of 3,000 calories instead of 3,400 calories as in Atwater's scale. This means that the standard unit has been shifted to allow for a lower degree of activity, not that Atwater's unit was too high for the activities which it represented.

In 1907 Langworthy, who had worked with Atwater, summarized and compared the results of all dietary studies made in this country and in other countries. He concluded (*659*):

> The results obtained the world over do not differ markedly from a general average of 3,000 calories of energy, and it is fair to say that although foods may differ very decidedly, the nutritive value of the diets (as regards energy) . . . is very much the same for a like amount of muscular work.

It is doubtless because of this statement that later scales in this country were generally based on a standard unit of 3,000 calories.

In 1917 Gillett made a thorough survey of all the data on children's energy needs, and suggested allowances for healthy children based on these figures (*411*). Even at that time most of the available data were from German studies. Much later—1931—Gillett's allowances were expressed in the form of a scale, based on an adult male unit of 3,000 calories (*412*).

In 1918, Lusk (*702*) set up standards and a scale based on 3,000 calories as the unit for the use of the Interallied Scientific Food Commission during the World War. His figures were based chiefly on estimates of energy output under different conditions as shown by calorimeter studies.

In 1921, more standards for children were suggested by Holt and Fales (*535*), based upon estimates of the factors which make up the demand for food and checked by dietary studies.

In 1927, Hawley (*500*) proposed a scale and standards for the use of the Bureau of Home Economics. These were based upon a very able summary and analysis of existing American scales and standards and did much to eliminate the confusion which had arisen in their use. She made it quite clear that a scale must always be used in conjunction with the standard upon which it is based. She found that Atwater's scale had often been used in conjunction with the standard adult male unit of 3,000 calories rather than that of 3,400 calories upon which it was based, with very misleading results. The energy unit of Hawley's scale was 3,000 calories.

In 1932, Roberts summarized all the results of dietary studies made on individual children from 1882 to 1932 (*973*). To these she added many studies of her own. She found that the energy requirements of girls were more closely related to their height than to their weight and proposed new standards for girls on this basis (*1177*), but she did not state her results in the form of a scale.

In 1939, as a basis for computing the number of energy requirement units to which family groups are equivalent, Stiebeling and Phipard (*1104*) suggested calorie allowances for men and women of given height and weight at each of four degrees of activity and for children at different age levels, as shown in table 7. The fact that a single figure is given for a wide age or activity range indicates the approximate character of these allowances. On this basis they compute a simple energy requirement scale using 3,000 calories, or the allowance for a moderately active man of 70 kilograms (154 pounds) body weight, as the unit. This scale has been used in all of the recent dietary studies made by the Bureau of Home Economics in summarizing data from families differing in size and composition.

TABLE 7.—*Food energy: Suggested daily allowances*

Description of individual					Suggested allowances	Requirement scale
Sex, age, and activity	Average height		Average weight			
	Inches	*Centimeters*	*Pounds*	*Kilograms*	*Net calories*	*Units*
Men, 20–59 years: [1]	68	173	154	70		
Moderately active work [2]					3,000	1.00
Very active work [3]					4,500	1.50
Light work [4]					2,700	.90
Sedentary work [5]					2,400	.80
Women, 20–59 years: [1]	64	163	132	60		
Moderately active work [2]					2,500	.83
Very active work [3]					3,000	1.00
Light work [4]					2,300	.77
Sedentary work [5]					2,100	.70
Boys:						
16–19 years	68	173	139	63	3,600	1.20
13–15 years	63	160	111	50	3,000	1.00
11–12 years	57	145	82	37	2,500	.83
9–10 years	53	135	68	31	2,400	.80
7–8 years	49	125	55	25	2,100	.70
4–6 years	42	107	40	18	1,500	.50
Girls:						
14–19 years	64	163	121	55	2,500	.83
11–13 years	58	147	89	40	2,400	.80
8–10 years	52	132	64	29	2,100	.70
4–7 years	42	107	39	18	1,500	.50
Children:						
2–3 years	35	89	29	13	1,200	.40
Under 2 years	30	76	22	10	900	.30

[1] A reduction of about 10 percent was made in calorie allowances for persons between the ages of 60 and 75, and of about 20 percent for those over 75 years. Some adjustments were also made for persons in each group whose height was above or below average.

[2] Moderately active work—standing or walking with moderately heavy loads.

[3] Very active work—rapid heavy lifting or pulling with exposure to weather.

[4] Light work—seated, with considerable arm or leg movement; or standing and walking with little lifting or strain.

Sedentary work—seated, involving little arm or leg movement.

PROTEIN REQUIREMENTS OF MAN

by D. Breese Jones[1]

IF there were any one "secret of life," protein might be considered to be at the heart of it, since protein is the essential stuff of which all living tissue is made. In animal and human bodies, proteins also enter into the chemical structure of some of those mysterious hormones that have such widespread effects. Proteins, in turn, are made up of simpler substances called amino acids, which have been called the actual building stones of the body. In this article, the author gives an account of these amino acids as they are now understood, in addition to summarizing what is known about our protein needs from the standpoint of quality and quantity.

SATISFACTORY NUTRITION for all animals requires that protein be supplied in the diet in sufficient quantity and that it be of the right kind. Protein is primarily the body-building material. It constitutes the chemical basis of all living cells, and without it life cannot exist. The organic substance of the organs and most of the tissues is made up principally of protein substance, and no other substance can take its place. On the average about 18 percent of the human body consists of protein. Hair, nails, skin, and muscle tissue consist almost entirely of protein.

Not only is protein required for the construction of new body tissues during growth from the tiny egg which marks the beginning of life to adult development, but there is also a requirement throughout life for the renewal and rehabilitation of tissues. Under certain circumstances, such as fasting or violent exercise, when the diet does not provide enough fuel material to supply the necessary energy, a draft is made on the body tissues. After wasting diseases there is a special requirement for protein food for restoration of lost muscular tissues. During pregnancy an additional demand is made for protein material to provide for the growth of the developing fetus.

Proteins can also serve as a source of fuel for maintaining body temperature and for muscular work. They have about the same fuel value as carbohydrates. The use of protein as a sole source of energy, however, is extremely wasteful and undesirable, both economically and physiologically. Fats and carbohydrates are the natural fuel foodstuffs. Consisting almost entirely of carbon, hydrogen, and oxygen, they burn completely within the body to gaseous products which are easily removed by the lungs. But when protein is oxidized there remain solid nitrogenous products which must be eliminated by the kidneys and liver. Economically, protein is the most expensive of the foodstuffs, and its use in the diet should be primarily to furnish those nitrogenous constituents that no other foodstuff can supply.

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The function of protein in supplying tissue building and replacing material is not its only role in the body. The essential units that protein supplies for this work are the amino acids, and it has recently been discovered that these acids or their derivatives are important constituents of the substances secreted by various glands. It is now quite generally accepted that many of the enzymes and hormones are protein material, or contain amino acid residues as essential parts of their structure. These substances do not enter directly into the structure of body tissue. The action of each one is specific, and is confined largely to some one particular task in regulating the many physiological activities upon which life and health depend. The amount required for performing their individual tasks is extremely small, so that in many cases they are present in the body in mere traces.

The digestion of protein is first started in the stomach by the action of pepsin, and later completed in the intestines by trypsin, erepsin, and other enzymes which are of a protein nature themselves. Glutathione, composed of three amino acids, glutamic acid, glycine, and cystine, plays a vital part in reactions involving oxygen—oxidation and reduction—within the cells.

Insulin, a hormone of the pancreas which largely regulates carbohydrate metabolism and controls the level of sugar in the blood, is composed almost entirely of nine amino acids. It is now prepared commercially and used extensively in the treatment of diabetes.

Thyroxine, an amino acid containing iodine, secreted by the thyroid gland, plays an important part in physical and mental development, and in differentiation as illustrated in the metamorphosis of tadpoles into frogs. The normal period required for the transition of tadpoles into frogs can be greatly shortened by feeding thyroid extract or thyroxine. This change may be brought about so prematurely that small frogs no larger than a fly often result. Deranged functioning of the thyroid may be manifested in a variety of ways. Striking examples are myxedema, a disease attended by chilliness, swelling, anemia, and mental and physical sluggishness; and cretinism, a condition resulting in dwarfism and idiocy as a result of cessation of physical and mental development. When treated with thyroxine patients suffering from these diseases tend to develop normally.

Adrenalin, or epinephrine, a product of the adrenal glands having a profound effect on blood pressure, is closely related chemically to the amino acid tyrosine.

There are doubtless many other enzymes and hormones in the body which require for their formation specific amino acids that must be supplied by the proteins in the food. The small quantities in which these substances occur do not make much extra demand on the body's requirement for dietary protein, but the demand continues throughout life, varying in kind according to age and circumstances. In the event of deficiency of amino acids in the food proteins, the elaboration of enzymes and hormones would probably proceed at the expense of the break-down of tissue proteins to meet the demand.

WHAT ARE PROTEINS?

The great bulk of the nitrogenous constituents of foods consists of protein. Protein rarely, if ever, occurs in natural foods in a pure or free state, but is usually combined or associated with other material, such as carbohydrate and fat. For this reason proteins are rarely determined in foods by quantitative isolation. Since all proteins contain nitrogen within a relatively narrow range, they are estimated on the basis of nitrogen content. The percentage of nitrogen found in the food multiplied by the factor 6.25 is taken as the percentage of protein. This factor was originally used because many proteins, particularly those of animal origin, contain very close to 16 percent of nitrogen. Many vegetable proteins, however, contain considerably more nitrogen, some as much as 18 percent or more. The indiscriminate use of the factor 6.25 consequently will not give in all cases strictly accurate figures for the protein content of foods. Protein is found naturally in the most nearly pure state in the white of egg, the curd of milk, and lean meat.

Chemically, protein is one of the most complex organic compounds, and its structure has long been and continues to be the subject of extensive investigation. Most proteins are composed almost entirely of the elements carbon, hydrogen, nitrogen, oxygen, and sulfur. Some also contain phosphorus and a small amount of other elements. They are characterized, however, by their nitrogen content. The term "protein," used as a class name to differentiate it from other substances, does not signify an individual compound. In fact, there are innumerable proteins differing from one another chemically and physically. They may have identically the same percentages of carbon, hydrogen, oxygen, nitrogen, and sulfur and still have very different properties.

PROTEINS DIFFER GREATLY IN NUTRITIVE VALUE

The question of protein requirements in nutrition is essentially a question of amino acid requirements. Not all proteins have the same value in meeting the requirements of the body for its specific nitrogenous needs. Some proteins are deficient or lacking in certain amino acids which are essential for the satisfactory growth and nutrition of the body. Such proteins are often referred to as "deficient" or "incomplete" proteins. When these constitute the sole source of protein in the diet, animals will not grow or be nourished properly, irrespective of the amount eaten. Consideration of the protein requirements in nutrition, therefore, involves not only the quantity, but also the quality or kind of protein.

In order to understand clearly how proteins may differ so greatly in their nutritive value, their chemical nature will be considered briefly. When proteins are digested in the alimentary tract they are successively broken down by the action of the different digestive enzymes into simpler and simpler fragments until they reach the ultimate units composing the protein molecule. These end products of protein digestion are the amino acids, of which some 22 or more are known. Some of them have been discovered only recently, and it is probable that others still remain to be identified. They are sometimes referred to as the building stones of which proteins are composed. Different proteins vary both in the proportions of these amino acids and in the way they are linked together in the molecule.

The amino acids, when pure, are white, crystalline solids. They all contain both acidic and basic groups of atoms. In some, the acidic and the basic groups balance each other. Such amino acids are neutral in reaction and are tasteless. In others, either the acidic or the basic group predominates, giving them sour and alkaline tastes, respectively. A few amino acids taste sweet. Chemically, an acidic group in one amino acid can combine with a basic group in another to form a new compound. This in turn can similarly combine with other amino acids, either of the same or of different kind, and so on until a huge and complicated protein molecule is formed. No one has yet succeeded in synthesizing a true protein, although a substance of high molecular weight having many of the properties of a protein has been thus prepared.

After complete digestion of the proteins the amino acids pass through the intestinal walls into the blood stream and are distributed throughout the body to the various tissues, where they are recombined in different ways and in different proportions to form the particular kinds of protein required for each tissue. Thus, the body does not use the proteins of the food directly for body building, but first breaks them down, and from the resulting building stones reconstructs new and different proteins to meet the specific requirements of each living cell.

Nature has imposed a peculiar limitation on the ability of the body to manufacture its own supply of amino acids. It can produce some, but for others it is entirely dependent upon the proteins in the food. Each one of the large number of different kinds of proteins which enter into the composition of tissue cells requires for its construction a different but very definite assortment of amino acids. If only one of the amino acids required for the synthesis of a given protein be lacking, that particular protein cannot be formed no matter how great a surplus there may be of the other amino acids.

Those amino acids that the animal body cannot manufacture but which must be supplied by the food are commonly referred to as "nutritionally essential" or "nutritionally indispensable" amino acids, and those which can be synthesized within the body, as "nutritionally nonessential" or "nutritionally dispensable." These terms are, however, somewhat misleading. Practically all the 22 known amino acids are constituents of the proteins of body tissue. They are all, therefore, essential for the construction of body protein, irrespective of whether they are supplied by the food or whether they have to be manufactured within the body. Glycine, for instance, which can be formed within the body, is a constituent of body proteins and in that sense is essential for nutrition of the body, but it is not essential that it be supplied by the diet. Lysine, on the other hand, cannot be synthesized by the body, and it is therefore essential that it be supplied by the diet. A preferable way to designate the two classes of amino acids would be "dietary dispensable" and "dietary nondispensable" or "dietary essential."

At present 10 amino acids are regarded as dietary essential (table 1). Young experimental animals will grow satisfactorily for short periods, at least, on a diet in which the 10 nondispensable amino acids constitute the sole source of nitrogen. When any one of the 10 is withdrawn from the diet, growth ceases or is greatly retarded. There is scant information, however, on the important subject of the requirements for the protein constituents in nutrition. Further work is needed, with observations covering the life span of one or more generations.

Table 1.—*Known amino acids and those that must be supplied in the diet*

Amino acids known as hydrolytic products of proteins				Dietary-essential amino acids	
Alanine	Histidine	Methionine	Thyroxine	Arginine	Methionine
Arginine	Hydroxyglutamic acid	Norleucine	Tryptophane	Histidine	Phenylalanine
Aspartic acid	Hydroxyproline	Phenylalanine	Tyrosine	Isoleucine	Threonine
Cystine	Isoleucine	Proline	Valine	Leucine	Tryptophane
Glutamic acid	Leucine	Serine		Lysine	Valine
Glycine	Lysine	Threonine			

Until recently, cystine was generally regarded as a dietary-essential amino acid. It has lately been shown, however, that methionine can replace cystine in the diet although cystine cannot replace methionine. This discovery would apparently remove cystine from the list of dietary-essential amino acids. On the other hand, it has been long known that the proteins of certain legume seeds, notably those of the common white bean, are not capable of supporting growth unless cystine is added to the diet. These proteins have a very low content of cystine, but have ample methionine. Casein is another protein having a rather low cystine content (0.3 percent). When fed at a level below 12 percent of the total weight of the diet, growth at a satisfactory rate will not result unless cystine is added. Like the white bean, casein also contains a relatively large amount of methionine. Whether cystine should be regarded as a dietary-essential amino acid or not, it certainly appears to be a limiting factor in the nutritive value of a number of proteins.

Although glycine and alanine are essential constituents of tissue proteins, they need not be supplied by the food because they can be formed within the body in quantities sufficient to meet all normal needs. They are therefore dietary-dispensable.

Satisfactory classification of all the amino acids cannot be made until further knowledge has been developed regarding their properties and biological behavior in the living organism.

In the discussion here of individual members of the group of dietary-essential amino acids, in connection with their occurrence in food proteins, it will be observed that reference is confined chiefly to lysine, tryptophane, and cystine. The reason for this is not that these are more important than the others, but that fairly accurate values are available for the quantities in which they occur in most proteins. Values for most of the other seven are very meager and approximate. In fact one of them, threonine, was so recently discovered that it has been determined only in a very few proteins. Determination of these amino acids in food proteins is being held back because of lack of satisfactory methods of analysis. Here lies a wide and very important field for future work.

From the foregoing considerations it is clear that the nutritional value of any food as a source of protein depends primarily on the extent to which it can meet the body's requirements for the dietary-essential amino acids. The chief proteins of some of the most important foodstuffs are incomplete, or deficient in some essential amino acid. Zein, which constitutes 40 to 50 percent of the total protein content of corn, is lacking in lysine and tryptophane. Young animals fed zein as the sole protein in a diet adequate with respect to the other dietary factors soon lose weight. When tryptophane is added they will maintain their weight, but they will not grow until lysine is also added. Gliadin, one of the two chief proteins of wheat, is very deficient in lysine, and will not support growth at a satisfactory rate unless lysine is added to the diet. Cooked phaseolin, the chief protein of the common white bean, like the proteins of other legume seeds belonging to the same botanical genus, requires addition of cystine in order to make it adequate to support normal growth. Gelatin is a conspicuous example of an incomplete protein, known to be lacking or deficient in a number of amino acids (valine, isoleucine, histidine, cystine, and possibly others).

DIGESTIBILITY OF PROTEINS

The nutritive value of a protein may be limited because of another consideration than amino acid deficiency. Proteins differ in digestibility. Some protein substances are scarcely acted upon by the enzymes in the digestive tract. Others may be only partially digested, leaving some of the amino acids in chemical combinations that cannot be assimilated and utilized for body building. A protein that cannot be digested in the alimentary tract to the extent that all its essential amino acids are made available for assimilation is in effect of no greater value nutritionally than one completely lacking in the amino acids that cannot be liberated.

The proteins of certain legume seeds, including the navy bean, lima bean, lentil, and others, are outstanding examples of food proteins that have a low nutritive value because of indigestibility. It has been pointed out that these proteins are deficient in cystine. When raw, even after the necessary addition of cystine, these proteins will not support normal growth. Heating for a short period, however, renders them digestible and capable of supporting satisfactory growth, after supplementation with cystine.

It is well known that the nutritive value of soybeans is greatly improved by heating, preferably in a moist condition. Analyses show that, in contrast with the proteins of the other beans just referred to, those of the soybean contain a relatively large quantity of cystine. Apparently in the raw state this amino acid is not available for assimilation, as shown by the fact that addition of cystine to the raw material produces the same beneficial effects as heating does.

Contrary to prevailing popular belief the whites of eggs are greatly improved after they have been heated enough to coagulate the protein. Not only is raw egg very poorly utilized, but it has definite toxic properties when eaten in relatively large quantities. Coagulated egg white is readily digestible and is a protein of good nutritive value, although somewhat inferior to the proteins of the yolk. Moderate cooking does not in general significantly impair the nutritive value of the proteins of most foodstuffs. In many cases their digestibility is improved and the availability of the amino acids increased. High temperature should be avoided because of the possible destructive effect upon some of the amino acids. Casein, the protein of milk, was found to lose much of its growth-promoting value when subjected to dry heat for 30 minutes at 140° C. (284° F.), but could be restored to its preheated value by the addition of lysine.

SUPPLEMENTARY RELATIONSHIP OF DIFFERENT PROTEINS

In order to correct amino acid deficiencies in the diet it is not necessary to add the required units in pure form. The same object can be accomplished more conveniently and more economically by employing proteins which contain the required amino acids. It has long been known by those who have studied practical dietetics that mixtures of protein foodstuffs are desirable. Foods containing incomplete proteins should be mixed with others which, although they too may be incomplete in themselves, will supply the mixture with adequate amounts of all the essential amino acids. Variety, as the keynote to an assurance of adequate diet, applies to proteins as well as to vitamins and mineral elements. The principle of supplementation also makes possible better utilization of low-priced foodstuffs, which as a class have a lower nutritive value.

Foods of animal origin, particularly meat, eggs, and milk, supply proteins of high nutritive value, from the standpoint both of digestibility and of amino acid content. An exception must be made of gelatin, which is one of the most incomplete proteins known. Gelatin, however, has a wide range of usefulness as a food, and is used extensively for desserts, cold soups, and in many other ways. The protein of ordinary muscle meat does not rank quite as high as that of eggs or milk. The glandular tissues-- liver, kidney, and sweetbread (pancreas)—contain protein of exceptionally high nutritive value. Of all natural foods milk not only comes the nearest to being a balanced food, for children particularly, but it contains in readily available form 18.7 grams (two-thirds of an ounce) of first-class protein to the pint, in addition to minerals, vitamins, carbohydrates, and fats. Animal proteins have a high content of dietary-essential amino acids which makes them very effective in supplementing many vegetable proteins. Nuts contain high percentages of proteins which have an adequate assortment of amino acids.

Cereals and legume seeds furnish some of the best-known examples of incomplete proteins. These proteins include zein (corn), gliadin (wheat or rye), hordein (barley), and phaseolin (common white bean). It should be emphasized that the cereal grains contain besides the incomplete proteins others which in themselves may be quite adequate. Wheat, for instance, contains besides gliadin about an equal amount of glutenin and smaller quantities of other proteins that have a higher nutritive value. The proteins of the germ and of the bran of wheat contain high percentages of the amino acids that are lacking in gliadin. Zein represents only about 40 percent of the total proteins of corn. The other proteins compensate to a large extent, if not wholly, for the deficiencies of zein. It has been generally regarded that whole corn as the sole source of protein in the diet is not adequate for growth. This view, however, is now open to serious question. Recent experiments have demonstrated that young albino rats will grow to maturity at a very satisfactory rate on a diet containing no protein other than that supplied by whole yellow corn. The cereal grains, however, are primarily energy foods and should not be depended on solely to supply the body's protein requirements, but shculd be supplemented with other protein foods that are good sources of the dietary-essential amino acids.

Seeds of leguminous plants, as a rule, have a high content of protein, but it is of low nutritional quality. The total proteins of the navy bean, lima bean, adsuki bean, field pea, and lentil are inadequate alone to support normal growth, because of two limiting factors—a deficient amount of cystine and a type of indigestibility especially when raw. A comparison of the amino acid composition of the proteins of these legume seeds with those of corn indicates a supplemental relationship. The bean proteins contain relatively large amounts of lysine, tryptophane, and histidine, in marked contrast to those of corn. The proteins of soybeans and peanuts present some striking contrasts to those of the other legume seeds. Chemical analyses show that the former contain a goodly proportion of cystine, and in feeding experiments their proteins have enabled young animals to grow at a satisfactory rate. The soybean proteins, however, are efficient only after they have been heated.

Little is known regarding the nitrogenous constituents of fruits and vegetables. Because of the relatively small amount of protein present, they play a minor role as substances in the diet which contribute to the growth and maintenance of body proteins. They are valued chiefly as sources of energy, vitamins, and mineral elements. On the other hand, the small amount of protein present may be of such a nature as to have a greater significance in nutrition than its quantity would seem to indicate.

QUANTITATIVE REQUIREMENTS FOR PROTEINS

The question of how much protein a person requires daily in his food to supply the various needs of the body for amino acids obviously depends upon a number of different factors. The two that have been chiefly considered in arriving at estimates are age and physical activity. During the early period of growth the demand for material for building new muscle and other protein tissue is very great. It has been estimated that during the first year of life about one-third of the protein intake is stored as body protein. In adult life the requirement for construction of new body protein is much more constant and is limited chiefly to replacement and maintenance.

It is generally agreed that persons engaged in vigorous muscular exercise or hard labor require more protein than those living sedentary lives. It has long been a debatable question whether physical exercise results in any material breaking down of muscle tissue, with consequent demand for additional dietary protein for tissue reconstruction. However, it is known that should there be an inadequate intake of energy food during the working period, tissue protein will be utilized to serve as the source of energy. In practice, statistical studies show that men engaged at hard labor do consume more protein than those engaged in sedentary occupations. The reason for this may well be that their total food intake is higher.

During pregnancy and lactation there is a marked increase in the demand for protein, for not only must the normal requirements of the mother be satisfied, but a supply must also be provided for the growing child. During many diseases there is a loss of body tissue which must be replaced during convalescence.

The quality of the protein is also a very important factor in any consideration of the quantity required. Because of great differences in the amino acid composition of proteins, it is impossible to estimate the total protein requirements without taking the quality of the protein into consideration. Individual characteristics, such as basal metabolism, tastes and dislikes, and variations in the requirements for endocrine secretions may also well have an influence on the amount of dietary protein required.

The earliest estimations on the amount of protein required were made largely in an attempt to answer the question, To what extent may the protein content of the diet of man be lowered with safety? They were based largely on statistical data showing the actual average amount of protein taken by different groups and classes of people. The reliability of such a method as a basis for determining the amount of protein actually required is evidently open to serious question, since there may be a vast discrepancy between the amount which experiment shows to be adequate and that based on the average consumption, which is largely determined by custom and habit as the result of instinct.

The experimental method commonly used for determining the protein requirements is carried out by means of metabolism studies in which the total amount of nitrogen in the food eaten is compared with the total nitrogen excreted in the urine and feces. When the amount of nitrogen ingested is equal to that excreted, the individual is said to be in nitrogen equilibrium. When the amount of nitrogen intake is greater than the output it indicates that the difference has been retained in the body for meeting its various requirements. A larger output than intake of nitrogen in a normal, healthy individual shows that the amount of protein eaten is below that required, and that the body is drawing on its own tissues and reserves to supply the deficit. When there is not enough protein nitrogen in the food eaten to meet all the normal requirements of the body, the more vital functions are taken care of at the expense of those which are less important for the support of life. It has been shown, for instance, that during starvation the body uses the protein of its own tissue in order to provide the needs of organs which are more vital for the prolongation of life. The excess of nitrogen output over the intake represents the nitrogenous byproducts resulting from the break-down of tissue proteins as a consequence *of an inadequate supply of protein* in the diet.

Theoretically, the daily amount of protein in the food necessary to maintain a person in a state of nitrogen equilibrium is a measure of the minimum amount of protein required under the prevailing conditions. However, the figure thus arrived at is only approximate. There are complicating factors, many of which cannot be accurately estimated, which make it impossible by this method to determine exactly the amount of protein required. The method used for determining protein, namely, multiplying the nitrogen figures by the factor 6.25, may involve errors. The quality of the protein in the food used with reference to its content of essential amino acids is not taken into account, nor is the question of its digestibility. There are other factors which could be enumerated.

During the first part of the present century a very liberal allowance of protein in the diet was advocated, both in Europe and in the United States. Statistical studies showed variation in daily protein consumption over a wide range. In Sweden, laborers doing hard work and having a perfect freedom of choice in their food were found to consume daily an average of 189 grams of protein. Similar groups in Russia used 132 grams. German soldiers in active service had a daily intake of 145 grams. Data obtained for laborers in Italy, France, and England represented, respectively, 115, 135, and 151 grams of protein intake daily. Surveys made in the United States on the food consumption of different classes during 1894 to 1904 on about 15,000 persons, including men, women, and children, showed that the average protein intake ranged between 100 and 175 grams per day. Other studies made on special groups, including lumbermen and college athletes, showed figures ranging from 160 to 270 grams. A group of professional men's families were found to consume an average of 104 grams daily. These results were taken at that time as representing actual protein requirements, but in fact they really indicate the result of differences in habits, customs, and circumstances rather than true physiological needs. Later there was a swing to the other extreme. The theory was advocated that the physiological needs of an adult under ordinary conditions could be met by a daily intake of protein as low as 50 grams or less. At the present time a protein requirement between the former extremes is quite generally accepted.

PROTEIN REQUIREMENTS IN THE LIGHT OF PRESENT KNOWLEDGE

Recent conclusions with respect to the desirable amount of daily protein intake in the food of man, reached as a result of careful studies made by authorities in the field of nutrition, are in close agreement. It is generally emphasized that the protein intake should not be limited to what may be regarded as the minimum amount theoretically required as indicated by results of metabolism experiments. It is not so much a question of how little protein a person can get along with and maintain what may be called a normal nutritive condition, but what is the amount required to give the maximum degree of health and well-being. It is generally considered desirable to allow a certain surplus, or margin of safety, above what may be actually necessary.

In a joint conference of representatives of the nutrition advisory committee of the Ministry of Health of Great Britain and the nutrition committee of the British Medical Association, it was agreed (*539*):[2]

> that accumulated evidence indicates that the total daily need for protein per man unit probably lies between 80 and 100 grams.[3] The precise amount of protein needed by any particular individual depends on weight, physique, occupation, habits, personal taste, age, while climate appears to be of some importance . . . There is a general consensus of opinion that a certain proportion of the total protein should be in the form of first class protein, i. e., protein of animal origin—eggs, milk, cheese, meat or fish. The desirable proportion of animal protein to total protein has, so far as our knowledge goes, never been exactly determined, but we are convinced from the evidence which is available that the young child and the expectant and nursing mother require relatively large amounts of first-class proteins—much more indeed than would be arrived at by simple calculation based on their man-value equivalent.

In any discussion on the amount of protein required by children during growth, particular emphasis should be placed on the character of the protein given. The animal proteins approximate more nearly the proteins of the human body than do those of vegetable origin and for this reason are preferred. For the growing child, therefore, the animal proteins, such as are furnished in milk, eggs, and meat, are distinctly of a higher grade than vegetable protein. Breast-fed infants are the best examples of good nutrition and growth. The proteins of woman's milk are the best adapted in amino acid composition for digestion and assimilation by the infant. Woman's milk contains about twice as much lactalbumin as does cow's milk. This protein, representing about one-sixth of the total protein of cow's milk, contains more of several of the dietary essential amino acids than does casein, the chief protein of cow's milk. Holt (*536*), an eminent authority on child nutrition, has arrived at the following conclusions:

> Healthy children take in their usual diet about 4 gms. of protein per kilo [2.2 pounds] body weight at the age of 1 yr., the amount diminishing to about 2.6 gms. at 6 yrs. of age, and remaining at about this value, or slightly below it, until the end of growth. Of this total practically two-thirds is animal protein. Thus there is in the usual diet about 2.7 gms. animal protein and 1.3 gms. of vegetable protein at the age of 1 yr., and about 1.6 gms. animal protein and 1 gm. vegetable protein at the age of 6 yrs. and thereafter. This quantity of protein may perhaps be regarded as the optimum and may therefore be recommended as the suitable intake for the growing child.

At the present time the general consensus of opinion of leaders in the study of nutrition with respect to the best proportions of protein in the diet is reflected in the report drawn up by the Technical Commission of the Health Committee of the League of Nations (*669*). The part pertinent to this question follows:

> In practice the protein intake for all adults should not fall below 1 gram of protein per kilo of body weight.
>
> The protein should be derived from a variety of sources, and it is desirable that a part of the protein should be of animal origin.

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[2] Italic numbers in parentheses refer to Literature Cited, p. 1075.

[3] A day's diet that would furnish an amount of protein within this range may be illustrated by the following menus: Breakfast, 1 orange, 2 slices of toast, 1 egg; Lunch, 2 slices of bread, 1 pint of milk, cup of custard; Dinner, 1 cup of soup, ¼ pound of steak, 1 potato, 1 serving of shelled lima beans, 1 serving of spinach, salad, dessert. Such a list would represent approximately 95 grams of protein. It is not intended that this list should represent a balanced or an adequate diet, either with respect to quantity or quality, but merely to give an idea of how much protein such meals would represent.

During growth, pregnancy and lactation, some animal protein is essential, and in the growing period it should form a large proportion of the total protein.

The following allowances of total protein are recommended:

Age (years)	*Grams per kilo [2.2 pounds] body weight*
1–3	3. 5
3–5	3. 0
5–12	2. 5
12–15	2. 5
15–17	2. 0
17–21	1. 5
21 and upward	1. 0
Women:	
Pregnant 0–3 months	1. 0
Pregnant 4–9 months	1. 5
Nursing	2. 0

PREVALENCE OF PROTEIN DEFICIENCY IN THE DIET

As a result of the rapidly growing interest in problems of nutrition and the increasing appreciation of the importance of proteins in the diet, the question is becoming more frequent, To what extent, if any, is there undernutrition as a result of inadequacy of dietary proteins? Because protein is so widely distributed in natural foodstuffs, it is believed by some that there need be little, if any, apprehension. The great difficulties involved in acquiring adequate data make it impossible at the present time to give a categorical answer to this question. The effects of deficiencies of most food factors other than proteins are readily recognized by specific symptoms. Deficiencies of vitamin B_1, vitamin C, vitamin D, and vitamin B_2 are manifested by beriberi, scurvy, rickets, and pellagra, respectively. The effects of protein deficiency, on the other hand, may be manifested by a variety of symptoms, any one of which may be also attributable to other causes. It is known that a low protein intake results in stunted growth and unsatisfactory reproduction and rearing of young; and cessation of ovulation resulting in failure to reproduce has been reported as caused by undernutrition with respect to protein. General ill health, mental and physical inefficiency, fatigue, lack of resistance to infection, and other ill effects have also been cited as the results of protein deficiency in the diet.

There is evidence that a normal individual eating a diet excessively low in protein tends to have low blood pressure and a low hemoglobin percentage. With a high protein diet, on the other hand, there is no rise in blood pressure and the hemoglobin is normal. Recent studies on the effect of different proteins on the rate of hemoglobin formation have shown that proteins of high nutritive quality are more effective for building hemoglobin than the same quantities of incomplete proteins, such as gliadin and gelatin. The formation or maintenance of normal hemoglobin values is more vital than growth. When the dietary protein is either qualitatively or quantitatively inadequate for growth, the rate of hemoglobin regeneration is significantly retarded.

Studies recently made on 1,000 residents of New York (*40*), living on liberal diets, normal as far as they knew, showed that 60 percent were getting 42 grams or less of protein daily. From this study in which a large proportion of a group living apparently in normal moderate circumstances was getting a daily quantity of protein so far below that generally agreed upon and recommended, it would appear that inadequate protein consumption in the United States may be far more prevalent than is generally suspected. On the other hand, Stiebeling and Phipard (*1104*) have recently made a very extensive study of the average per capita consumption of protein by white and Negro families in different regions in the United States at different levels of food expenditure. The consumption of protein was found to increase as the food expenditures rose. The authors conclude:

> Considering the proportion of families at each level of food expenditure, as well as the protein content of the diets, it would appear that less than 2 percent of the white families represented by this study purchased food furnishing less than 45 grams of protein a requirement unit[4] a day. The diets of 25 percent of these families provided 70 grams or less of protein a requirement unit a day; those of 50 percent, 82 grams or less; while those of 75 percent approximated 95 grams or less of protein a requirement unit a day. There is little likelihood of a serious deficiency in the quantity of protein in diets of many families of employed workers.

In more detail, this study showed that with a weekly food expenditure of $0.63 to $1.24 per person, the diets of southern white and Negro families furnished, respectively, averages of 52 and 51 grams of protein. When the food expenditure was $1.25 to $1.87 the diets of white families averaged from 59 grams in the mountain region to 65 grams in the East South Central region. For the same expenditure the food supply of southern Negro families furnished an average of 70 grams of protein a unit a day, although 4 percent of the diets furnished less than 45 grams of protein, and 43 percent between 45 and 69 grams a day. A weekly food cost of $1.88 to $2.49 supplied an average of 74 to 80 grams of protein per day in the case of white families in different regions, and 89 grams in the diets of southern Negro families. With weekly food expenditures of $2.50 to $3.12 the average protein content of diets of white families ranged from 86 to 94 grams. About one-half to three-fourths of the diets furnished between 70 and 99 grams, and most of the remainder between 100 and 120 grams a unit a day. At the same level of food expenditure the diets of all Negro families furnished at least 67 grams of protein, and three-fourths of the diets furnished more than 100 grams a unit a day. At a food expenditure level of $3.13 to $3.74 a person a week the average protein content of diets ranged from 97 to 109 grams a unit a day. At expenditures above $3.74 the averages exceeded 110 grams, and all families had diets furnishing more than 70 grams a unit a day.

Aside from economic restrictions certain customs and habits might tend to make protein consumption inadequate, among which may be mentioned voluntary restriction of food consumption for the purpose of reducing body weight, excessive consumption of carbohydrates and sweets, especially by children, and the use of an unduly large amount of proteins of poor quality in proportion to the total protein intake.

THE EFFECT OF HIGH CONTENT OF PROTEIN IN THE DIET

The possible injurious effect on the body of a large quantity of protein in the diet has long been a question that has engaged the attention of students of nutrition and pathology. Because of the fact that the nitrogenous waste products of protein metabolism in the body are excreted chiefly through the kidneys, it has often been held that an excess of protein in the diet overtaxes those organs, with injurious effects on their structure and functions. Recent experimentation has shown that an abnormally high proportion of protein in the diet results in a marked increase in the size of the kidneys, but that there is no apparent damage done to the tissue or to the functioning of the organs, which recede to their original size when the protein intake is lowered. These changes merely indicate a physiological response to increased functional demands. These results of animal experimentation find confirmation in studies that have been made on certain human races, such as the Eskimos, who subsist largely on meat and consequently have a very high protein intake. No evidence has been observed of impaired renal (kidney) function as a result of the high concentration of protein in their diet.

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[4] A nutrition-requirement unit is a moderately active man weighing 154 pounds. The amount of food required by such an individual is taken as a standard.

Notwithstanding the primary importance of the kidney in protein metabolism it might be possible that other body functions may be impaired by unduly large amounts of dietary protein. Lately attention has been given to various phases of the reproductive cycle. High concentrations of protein had no deleterious effect on ovulation, nor were any toxic symptoms observed during gestation even when diets containing as high as 70 percent of protein were fed. Lactation, however, was adversely affected unless the diet supplied an adequate amount of vitamins. From available data it appears that not until the maternal organism feels the stress of the elaboration of milk does a high level of protein in the diet exert an unfavorable influence.

MINERAL NEEDS OF MAN

IN comparatively recent years there have been many discoveries about minerals and vitamins that have completely changed our ideas of human food needs. Here different authors deal with the various minerals—calcium and phosphorus, iron and copper, iodine and fluorine, and finally numerous "trace elements," some of which are needed by the body in quantities so small as to defy analysis by ordinary chemical methods. Some of the findings given in this article are well established; others are so new as to be still on the border line of uncertainty.

CALCIUM AND PHOSPHORUS REQUIREMENTS OF HUMAN NUTRITION

by Henry C. Sherman [1]

CALCIUM REQUIREMENTS

CALCIUM is the outstanding element of the mineral matter which gives shape and permanence to the body's framework; which endows our bones with the strength, and our teeth with the hardness, that they need. In the construction of a normal human body nature uses more of calcium than of any other mineral element (fig. 1); and while calcium is prominent also in our natural environment, yet there is a serious calcium problem in nutrition, partly because so many of the human family have drifted away from the use of natural foods and eating habits and partly because the calcium compounds which are abundant in nature are relatively insoluble (or, to speak more scientifically, are but sparingly soluble). The sparing solubility or relative insolubility of the chief compounds or natural forms of calcium (the chief natural lime salts of rocks, soils, foods, and bones) does handicap the acquisition of calcium for our bodies from our environment. In fact if we except the highly special problem of iodine supply in goitrous regions, it is probable that ordinary dietaries are more often deficient in calcium than in any other one element. But rather than feel aggrieved that nature has imposed this handicap upon us, we should reflect that without this relative insolubility of natural lime salts there would be no such strength of bones or hardness of teeth as we possess; it would be a world for invertebrates only. Instead of placing us in such an invertebrate world, nature endows us with both backbones and brains, and invites us to apply our full endowment to our nutritional problems.

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Of the relatively large amount of calcium that belongs to our bodily structure, 99 percent or so is contained in the skeletal system, i. e., the bones and teeth with their immediately attached connective tissues. But while only about 1 percent of the body's calcium is, at any one time, circulating in the blood and permeating the soft tissues, it is performing highly essential functions there. Upon the presence of right amounts and proportions of calcium (or calcium ions), among other things, depend the normal properties and behavior of the fluids and soft tissues of the body, such as the blood, the muscles, and the nerves. To mention but two examples (for the problem of this article is essentially quantitative and its qualitative introduction must not be unduly prolonged), the contractility of the muscles, including the alternate contraction and relaxation of heart muscle which constitutes the beating of the heart, depends upon their being constantly bathed with blood or lymph containing the physiologically normal amount of

Figure 1.—Milk is one of the foods rich in calcium, which nature uses in greater quantities than any other mineral element for the construction of normal human bodies.

calcium, both as calcium concentration and as relative proportions of calcium salts to other salts (or calcium ions to other ions) present; and upon calcium depends also the clotting power of the blood, which is our safeguard against fatal bleeding from any slight break in the wall of any blood vessel. Small as is the concentration of calcium in our soft tissues and body fluids, its constant maintenance within the limits of the normal zone is a matter of utmost importance.

MINIMAL NEED FOR NORMAL ADULT MAINTENANCE

The quantitative study of the calcium requirement is best begun with the consideration of the amount needed for simple maintenance of the normal adult, for the logic of the problem is here the most direct, and the available data are the most certain. We shall then be proceeding from the simpler to the more complex, and from the better known to the less well known, when we go on from the need for normal maintenance to the added needs of pregnancy and lactation, of growth and development, and of such abnormalities, if any, as are to be studied.

The general plan of investigation of the requirement for maintenance is to find the smallest intake to which the body can adjust its expenditure or output, so as to be in essential equilibrium or even balance. This might also be called the lowest calcium level to which the body can adjust itself without continuing loss of calcium—the minimal-adequate level for maintenance. It depends on the fact that calcium used by the body is continually being excreted after it is used. Even when calcium-free food is eaten, calcium is excreted, which shows that daily needs are being met by drawing on the stores in the body itself. Finding the smallest intake and output that will balance therefore shows the minimum amount the body needs to maintain itself.

The actual experimentation to ascertain this level consists in the feeding to a healthy, cooperative person—or the eating, if the investigator is himself to be the subject—of a prearranged ration or series of rations, determining by chemical analysis the amounts of calcium entering and leaving the body per day, until one finds for the given subject the minimum level at which equilibrium or even balance of intake and output can be established and maintained. In the practical planning, operation, and interpretation of such experiments one must remember that if the body is well nourished at the start, its tendency is to establish equilibrium not only at the level of needed intake but also at any higher level at which calcium may be supplied.[2] In the actual operation of such an investigation, therefore, one takes as the measure of requirement in each instance the minimum level of output observed in a period of sufficient length, when the intake is the same as or slightly less than the observed output.

Systematic experimentation to ascertain the calcium requirement of normal maintenance was undertaken by cooperation between the Department of Agriculture and Columbia University some three decades ago (*1054*)[3] and was continued in collaboration with the New York Association for Improving the Condition of the Poor. In 1920, the writer brought together (*1042*) the findings of the 97 calcium-balance experiments then available which were judged to constitute valid evidence on the problem of the calcium requirement of normal adult maintenance in human nutrition. The mean maintenance requirement thus found was 0.45 gram per day.[4] This average as a rock-bottom minimum for normal adult maintenance has been widely used as a base line from which to estimate desirable allowances and dietary standards. After 16 years it appeared, from the viewpoint of the same method of compilation and interpretation, that (*1048, pp. 280-281*)—

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[2] This is also true of phosphorus, of protein, and of iron. Early indications of protein requirement were too high, and some present indications of iron requirement probably are too high, because of experiments in which the intakes were not sufficiently low and uniform.

[3] Italic numbers in parentheses refer to Literature Cited, p. 1075.

> If all applicable data published more recently than the above were now included, the average would apparently be raised slightly; but so little that we would not be repaid in accuracy for the inconvenience of changing the accepted approximate average.

Simultaneously and independently the more recent data were being collated by Leitch (*675*) who, employing an entirely different method of interpretation, reached the conclusion that the data point to 0.55 gram per day as a more correct estimate of the true requirement. And more recently Hye (*566*), using the same data as Leitch but a still different method of interpretation, arrives at an estimated average of 0.52 gram per day.

Although it is obvious that 0.55 and 0.52 are, respectively, 22 and 15 percent higher than 0.45, yet in view of the fact that the three figures are arrived at by three different interpretations of the experimental data, it may fairly be said that the minimal level of calcium intake for adult maintenance is now established with a high degree, not of precision, but of probable validity at approximately 0.5 gram per day.

While we may well regard this as a significant base-line figure or average minimum, it is important also to recognize (1) that as an expression of minimal need it covers only the average case, not all normal cases; and (2) that to provide for minimal need is not necessarily to provide what is required for thoroughly satisfactory nutrition.

If calcium requirement is to be understood as the amount required for fully satisfactory nutritional condition in all normal cases, then it must be set enough higher than 0.5 gram to cover physiological variability, and also to cover the difference between a minimal and something approaching an optimal level on which to maintain calcium equilibrium.

Estimate for Individual and Chance Variations

When, nearly 20 years ago, the teaching of dietetics began commonly to include the working out of dietaries to supply required amounts of some of the mineral elements as well as of protein and calories, it became necessary to set (conventionally, and primarily for the purpose of teaching practical dietetics) an estimate of calcium requirement which would presumably cover the minimal maintenance needs of all normal adults, consistently with the above finding of 0.45 gram as the average of data ranging from 0.27 to 0.82 gram in the individual cases. For the purpose of covering these individual and accidental fluctuations in actual need, an allowance of 0.68 gram per day, which provides a margin of 50 percent over the base-line average of 0.45 gram, came into very general use; and, probably because of this use, it tends to take on more weight of significance than its origin justifies. Both aspects are reflected in the following paragraph from a recent official publication (*1104*):

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[4] The probable error is ±0.008 gram and the standard deviation 0.12 gram. The 97 cases included in this average showed a coefficient of variation of 27. The mean thus found was not simply the "average output over an arbitrarily chosen range of intakes"; for while it was recognized that intake must be low enough to put the body to the test if the balance is to throw reliable light upon the requirement, each case was studied critically from all the viewpoints suggested by direct personal experience in the laboratory as well as library work of such investigations, extending through the preceding 15 years.

> The utilization of both calcium and phosphorus is influenced by a number of factors, including the ratio which they bear to each other, the quantity of vitamin D supplied by sunlight or food, and the quantity of fat in the diet. . . . To allow for the variation likely to be encountered in everyday foods, and to safeguard those persons whose requirements are higher than average, a 50-percent margin has been added to average minimum requirements in formulating dietary allowances. These additions bring the allowances for acceptable diets to 0.68 g of calcium and 1.32 g of phosphorus a man a day.

The allowance of a margin of 50 percent above the average minimum for normal adult maintenance can now be given the clear definition which it has always needed. It is an estimate intended to cover individual variations of minimal nutritional need among apparently normal people and accidental fluctuations within the range of normal variation in the utilizability of the calcium of the food supply.

Fifty percent above the average minimum as found in 1920 is the allowance of 0.68 gram hitherto used in many governmental calculations and publications and in much of the teaching of dietetics. Consistent with the recent increase of the base line of the average minimum to 0.5 gram, as above explained, is the current League of Nations recommendation of 0.75 gram of calcium per day for normal adult maintenance (*670*). Inasmuch as the normal need of some individuals may be as high as 0.82 gram, the recommendation of the League of Nations seems preferable to any lower figure.

It is important to emphasize, what is apparently not yet generally realized, that this allowance provides only for variations in the minimum and does not attempt to define the optimum.

Evidence on which to base sound discussion of optimal intakes of calcium is now beginning to be available, however.

REQUIREMENT FOR OPTIMAL NUTRITION

Any attempt to discuss optimal nutrition should take account of the entire life cycle and of the launching of a new generation at least as vigorous as its parents.

Obviously, even if the control of living conditions throughout whole lifetimes and successive generations of human beings could be accomplished, something like a century would be required for the gathering of adequately comprehensive data directly from our own species. Meanwhile, however, much is being learned from full-life and successive-generation experiments with laboratory animals of species whose nutritional chemistry is known to be, in this and many other respects, very closely parallel to our own. Such a species is the rat, which presents also the great merit of promptness in the completion of its normal life history—its life cycle being only one-thirtieth as long as ours.

The problem of the level of calcium intake which results in the best nutritional well-being throughout the life cycle and successive generations is now being studied in carefully controlled experiments with several hundred laboratory rats of a colony whose hereditary and nutritional background is exceptionally well known. And, while this investigation is still being extended in some directions, it is now reasonably conclusive on the points to which it gave first attention, which include the quantitative relation between the minimal-adequate and the optimal levels of calcium intake when the dietary starting point is comparable with that of the majority of our population (*658, 1045, 1050, 1051*).

In these experiments successive improvements in nutritional well-being have resulted from successive increases of the calcium content of the dietary up to levels well over twice, and more probably at least three times, the level of minimal adequacy. Long and comprehensive study makes it scientifically convincing that such health responses to improvement of the food supply as demonstrated and measured in experiments with the rat are well within the probable corresponding responses of human health (*1046*). For optimal nutrition, therefore, we must estimate the calcium requirement at not less than 1 gram per day for adult maintenance.

CALCIUM NEED DURING PREGNANCY AND LACTATION AND OPTIMAL ALLOWANCES FOR ADULTS

The Health Organisation of the League of Nations sets the calcium requirement for pregnant and lactating women at 1.5 grams per day (*670*). This, of course, is an attempt to express the average need of such women in a round figure for everyday use in the promotion of nutritionally adequate concepts of food supply. Its use as such is entirely consistent with appreciation of the fact that the need of a given individual is higher in the later than in the earlier stages of pregnancy; and that during lactation the requirement for equilibrium of intake and output of calcium depends very largely upon the amount of milk produced.

Stiebeling and Phipard (*1104, p. 50*) cite the League of Nations' standard of 1.5 grams of calcium per day for pregnant and lactating women with apparent approval, and suggest that a population allowance for women of 20 years and over be 30 percent above the corresponding allowance for men of 20 years and over. Such a margin should doubtless be allowed in estimates of minimal needs; but the lifetime studies of hundreds of experimental animals make it seem probable that when the objective is optimal nutrition men can use to the advantage of their health and efficiency the same liberal level of calcium intake as is best for women.

From the evidence thus briefly sketched it follows that with the requirement—in the sense of estimate of minimal need with allowance for variations—now put at about 0.75 gram per day for adult maintenance, the women of the population should have an average of about 1 gram per day to provide for the occasional exercise of the functions of pregnancy and lactation without undue tax upon the mother; and that the men of the population should also have an average of about 1 gram of calcium per day; if they are to be nutritionally at their best.

That liberal provision of calcium for the added needs of pregnancy and lactation is of great importance is well illustrated by the comprehensive review of Garry and Stiven (*409*) and the more recent work of Toverud (*1145*).

CALCIUM REQUIREMENTS OF GROWTH AND DEVELOPMENT

Notwithstanding the fact that the unborn child probably takes about the same amount of calcium from its mother whether she be well- or ill-prepared to spare it, all babies are born calcium-poor in the sense that the body of the newborn contains a lower percentage of calcium than does that of a normal adult.

It follows that during its growth and development the body must increase not only its amount but also its percentage of calcium, and thus that there is an accentuated need for calcium over that for body-building nutrients of other kinds. Thus the growing child needs a calcium intake high not only as compared with its size, but high also as compared with its energy (calorie) and protein requirements.

A study, both extensive and intensive, of calcium balances of children from 3 to 13 years old, especially as influenced by differences in the calcium content of the food, was carried out by cooperation between Columbia University and the New York Association for Improving the Condition of the Poor (*1048, pp. 283–285; 1052*). The results showed that different children of a given age-range have quantitatively different capacities for calcium retention, with corresponding differences in the amounts of food calcium needed to enable them to do their best. As there is no practicable method of distinguishing those of higher from those of lower need, it was recommended that children's dietaries be planned to contain 1 gram of calcium per child per day in order to provide for the needs of all cases. Daniels (*257*) has particularly emphasized the fact that liberal provision of calcium and vitamin D throughout earlier ages influences the capacity for retention and therefore the amount needed for optimal retention at a given age; that is, the more calcium the body already has, the less it will retain. Other investigators have further developed the differences of retention capacity due to the extent to which the body is already saturated, or to which it is still calcium-poor at a given age and size (*355, 989*). But as pointed out by Rose (*983, 1938 edition, pp. 169–171*) the actual data of Daniels' balance experiments show very little difference in the quantitative need as indicated by these and by both the earlier investigations above noted and the more recent and very extended studies of Jeans and Stearns (*585*). The latter indicate anew, with great emphasis and for all ages, the desirability of not less than 1 gram of calcium per child per day in order to provide for such individual differences as are apt to be met in ordinary normal experience. Particularly noteworthy is their repeated warning, even in an article primarily devoted to the vitamin D requirement (*585*)[5] that while vitamin D is a desirable safeguard against undue difficulty of calcium and phosphorus assimilation, emphasis upon the vitamin is never to be understood as permitting any lowering of our standard of calcium requirement.

Leitch (*675*) estimated that children should receive between the ages of 6 months and 2 years 0.8 gram; from 2 to 9 years 0.9 gram; at 9 years 1.0 gram; and thereafter an increasing amount reaching nearly 2 grams at about 15 to 16 years. The last-mentioned very high figure is largely due to her belief that the well-developed body should reach a much higher calcium content than most students have thought probable of attainment. As already mentioned, it has also been emphasized by Daniels and coworkers (*257*), by Fairbanks and Mitchell (*355*), and by others that if calcium is liberally supplied and well retained at early stages of development, the rate of retention in the later stages of growth will be less and therefore such high intakes as the maximal suggestions of Leitch will be uncalled-for.

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[5] Many findings of calcium balance experiments not yet published in full were presented and discussed by Dr. Stearns before the American Institute of Nutrition, at Baltimore, 1938.

The generally accepted American standard of 1 gram of calcium per child per day is, therefore, regarded by most students of the subject as being well sustained by the abundant evidence of recent investigations. This standard for children was adopted at the November 1937 meeting of the League of Nations' Technical Commission on Nutrition (*670*), and it is reaffirmed by Stiebeling and Phipard (*1104*).

PHOSPHORUS REQUIREMENTS

The phosphorus requirement of normal adult maintenance has been studied by means of balance experiments on the same principle as described for the study of the calcium requirement.

While the amount of phosphorus in the body is not so large as that of calcium, a very much larger quantity and proportion of the phosphorus belongs to the more active tissues, and so, as would be expected, there is a more rapid turn-over of body phosphorus than of body calcium. The average of 95 phosphorus-balance experiments which were deemed valid for the purpose, indicated a requirement of 0.88 gram of phosphorus per 70 kilograms (154 pounds) of body weight per day (*1043*). The average of 34 experiments with men was 0.124 gram per kilogram, and that of 61 experiments with women was 0.127 gram per kilogram. Since this difference is insignificant, the phosphorus requirement of maintenance appears to be proportional to body weight irrespective of sex.

The individual data were less variable than the corresponding data for indicated calcium requirement, so that the conventional addition of a 50-percent margin yields a standard allowance higher than the highest individual requirement found (1.32 grams allowed as against a maximum finding of 1.20 grams); whereas the corresponding allowance for calcium was lower than the highest individual requirement found (0.68 allowed as against a maximum finding of 0.82 gram). Thus the standard allowance that has commonly been used in dietary calculations and interpretations of the adequacy of food supplies has been 10 percent more than sufficient to cover actually recorded individual variations in the case of phosphorus, and 17 percent less than sufficient to cover the correspondingly recorded individual variations of indicated calcium requirement of normal adult maintenance. Yet even with this use of a relatively higher base line of interpretation, actual family food supplies show far fewer cases of shortage of phosphorus than of calcium. The significance of this is markedly increased by the further fact that the recent and current full-life experiments with laboratory animals the chemistry of whose nutrition is strikingly like that of man in this respect shows the need for a hitherto unsuspectedly large margin of calcium specifically if optimal nutritional well-being is to be attained and maintained.

Hence on critical analysis from the viewpoint of present-day knowledge (of which space does not permit a fuller account) it appears that the man-per-day standard allowance of 1.32 grams of phosphorus for adult maintenance is fully as generous with respect to now known need as is the allowance of 1.0 gram of calcium per day here advocated.

Thus standards for dietary calculations and for the interpretation of nutritive values of food supplies should, in the light of present knowledge, advance the calcium allowance to 1.0 gram in place of the hitherto conventional 0.68 or the League of Nations' suggestion of 0.75, while continuing the phosphorus allowance of 1.32 grams.

PHOSPHORUS REQUIREMENT IN PREGNANCY AND LACTATION

The additions that pregnancy and lactation make to the nutritional needs of the body are relatively less pronounced in the case of phosphorus than in the case of calcium; so that the phosphorus problem is not nearly so serious as is the calcium problem. This is true for a combination of reasons.

First, as has just been explained, the long-standing conventional allowance of 50 percent above the average measure of minimal adequacy in each case is, as we can see in the light of the fuller knowledge of today, a more generous insurance for meeting the individual's fluctuating needs for phosphorus than for calcium. Second, as has been shown, the data of phosphorus-balance experiments are sufficiently numerous for both men and women to justify quantitative comparison of their separate averages, and these are found to be essentially the same per unit of body weight. Hence when, as often happens in practice, the allowance of 1.32 grams of phosphorus per day is adopted for men and women alike (as it is adopted by Stiebeling and Phipard (*1104*)), the women, inasmuch as they average about four-fifths the body weight of men, are thereby given an additional 25 percent for whatever additional needs they may encounter; whereas, according to Leitch (*675*), lower body weight does not afford a corresponding insurance in the case of calcium. Third, the actual material transferred by mother to young both in pregnancy and lactation is relatively richer in calcium than in phosphorus. In the newborn baby, and in milk, there is more calcium than phosphorus; whereas all current dietary standards for adults and all (or practically all) American and European food supplies furnish more phosphorus than calcium.

As yet there is no evidence as to just how much more than actual need constitutes the optimal intake of phosphorus. By analogy with protein, however, it seems probable that a moderate margin is as advantageous as a larger one.

In view of all the foregoing facts, the Stiebeling-Phipard standard of 1.32 grams of phosphorus per day as an average allowance for all women of 20 years and over may be taken as expressing the best knowledge of today.

PHOSPHORUS REQUIREMENTS OF GROWTH

Assuming the now well-established measures for the prevention of rickets, there remains scarcely any reason to fear shortage of phosphorus in children's dietaries in which the calorie, protein, and calcium requirements are met. Hence there have naturally been less numerous phosphorus-balance than calcium-balance studies with children. In the work of Sherman and Hawley (*1052*), in which phosphorus balances were determined simultaneously with calcium balances in many experiments with children, it appeared that 1 gram of phosphorus per child per day is ample for all nutritional needs, and this has since been so generally used that it may now be regarded as an accepted standard allowance. Stiebeling and Phipard (*1104*) use 1 gram per day for boys up to 8 and girls up to 10 years; 1.2 grams for boys of 9–12 and girls of 11–19 years; 1.32 grams for boys of 13–19 years and adults 20 years and over.

RATIOS OF CALCIUM TO PHOSPHORUS

Experimental rickets is most easily induced by means of diets abnormally high in calcium and low in phosphorus, or abnormally high in phosphates and low in calcium. Thus it came about that the calcium-to-phosphorus ratio was frequently mentioned in the discussions, first of rickets and then of calcium and phosphorus metabolism generally. Convenient as it may be for reference, it seems probable that the habitual discussion of the ratio as such in considering the calcium and phosphorus requirements in normal nutrition tends rather to confuse than to clarify. For there is and can be no one best or most logical ratio. The ratio of needed calcium to needed phosphorus is perpetually changing with the development of the body from infancy to adulthood; and in the later stages of pregnancy and in lactation it is again different from that of adult maintenance. Full discussion of this fact would be too long and complicated for this article. But it may perhaps supply a key to the situation to point out that bone building calls for about twice as much calcium as phosphorus, while the mere maintenance of a fully developed adult calls for about twice as much phosphorus as calcium. In all the earlier years of a person's life, as also in the later months of a mother's pregnancy, supplying bone-building material is a large part of the responsibility of the food. Again in lactation the mother's food must meet, only now through the mammary glands instead of through the placenta, a nutritional need for support of the growth and calcification of bone tissue, with greater accentuation of calcium than of phosphorus requirement.

THE CONCLUSIONS IN BRIEF

The calcium requirement of adult maintenance is a phrase which in the light of present-day knowledge requires further specification to be explicit. If taken to mean the smallest amount that may be trusted to meet bare needs of normal maintenance with fair allowance for individual variations, the so-called standard of 0.68 gram may now better be advanced to 0.75 gram as advocated by the League of Nations' Technical Commission on Nutrition. If, however, requirement is taken to mean the amount needed for best results, recent and current experimental evidence indicates an allowance of not less than 1.0 gram per day.

Correspondingly for pregnant and nursing mothers, Stiebeling and Phipard's suggestion of 1.0 gram of calcium per day may be considered a minimum expression of requirement, and the League of Nations' recommendation of 1.5 grams as a tentative attempt at setting up a presumable optimum.

As a result of careful study of the somewhat complex situation briefly outlined in this article, it is believed that an allowance of 1.0 gram of calcium per child per day without distinction of age or sex is the most scientific and serviceable expression of the calcium requirements of growth and development.

For many purposes it may also be serviceable to use the simple standard of 1.0 gram of calcium per capita per day as an expression of the nutritional requirement of a population and as a guide to the evaluation of the nutritional adequacy of its food supply.

The phosphorus allowances of Stiebeling and Phipard are: 1.32 grams per day for all adults 20 years and over and for boys of 13 to 19; 1.20 grams for boys of 9 to 12 and for girls of 11 to 19; and 1.0 gram for all boys up to 8 and all girls up to 10 years of age. In the writer's opinion these may be taken as reflecting present-day scientific evidence as to the presumable phosphorus requirements for approximately optimal nutrition.

Recent research establishes the reality of the distinction between the merely adequate and the optimal in nutrition; but further research is needed to establish the precise position and requirements of the actual optimum.

IRON AND COPPER REQUIREMENTS

by Mabel A. Dickson[6]

IRON

The study of iron in foods and its function in nutrition has progressed so rapidly during the past few years that it is difficult to gain a proper perspective on the progress made. Some findings that seem now to be of the greatest importance may soon be discarded, whereas a finding at present obscure may be heralded as an important landmark in the future.

The discovery that only part of the iron in food is available for use by the body while the remainder passes through the digestive tract unchanged was largely responsible for a recent impetus to the study of iron requirements. This discovery revealed the lack of knowledge concerning the absorption and utilization of iron by the body. The acceptance of the new theory that the amount of iron retained in the body is regulated by the amount absorbed rather than by the action of the intestine may serve as an incentive for further research.

The iron requirements for human beings are based on few experimental studies. Until carefully controlled tests have been made on a large number of individuals in a state of buoyant health, the present requirements must continue to serve as a guide in nutrition. Certainly, until more is known about the utilization of iron in the body and the factors affecting the content of available iron in foodstuffs, it would seem wise to adopt generous rather than low allowances.

The daily allowances of iron to be discussed in this article may be summed up as follows (in each case it is assumed that the individual is normal and healthy):

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	Milligrams		Milligrams
Infant	[1] 0.36	Man	12–15
Preschool child	[1] .27	Woman before menopause	17
Boys, 5–11 years	9–11	Pregnant woman	20
Boys over 11 years	13	Nursing woman	17–20
Girls, 5–11 years	9–11	Woman after menopause	12–15
Girls over 11 years	13–15		

FUNCTION OF IRON IN THE BODY

The total amount of iron in a healthy adult's body is between 3 and 4 grams, or about one-tenth to one-seventh of an ounce—not much more than there is in a shingle nail. Of this, about 2 to 3 grams is contained in the coloring matter of the red blood cells—hemoglobin—and functions in the transportation of oxygen through all the arteries and capillaries to the innermost cells of every organ in the body. The remainder, except for a very small amount of unavailable iron in the body tissues, is stored in the liver, bone marrow, and spleen where it is ready for conversion into hemoglobin when needed by the body.

The proportion of iron in the diet that is absorbed and can be used for hemoglobin formation depends partly upon the foodstuffs. Experiments apparently show that under the most favorable conditions the available iron seldom exceeds 60 percent of the total iron content of the diet, so that to obtain a given amount it is necessary to consume nearly twice as much as the iron content of the foods would indicate. Then, too, all persons who eat similar foods do not necessarily have the same concentration of hemoglobin in their blood, for, besides different abilities to use available iron, there are differences in ability to manufacture hemoglobin.

The bone marrow has been depicted (*452*) as a gristmill with three hoppers supplying the materials for making red cells. One hopper supplies protein, fat, carbohydrate, vitamins, mineral salts, and water, which are necessary for the formation of body substances in general. The other two hoppers provide the specific elements necessary for hemoglobin formation—iron and a factor that matures red cells and prepares them for withdrawal from their storage place, the bone marrow. This factor is formed by the action of a secretion of the stomach on food elements and is stored in the liver.

Normally the three hoppers are full and are acting efficiently to maintain a normal balance between the formation and destruction of red cells. Nearly a trillion red cells and 25 grams (almost nine-tenths of an ounce) of hemoglobin must be formed daily and be free to circulate in the blood stream. This involves a daily utilization of about 90 milligrams of iron, which is considerably greater than the daily intake. The excess over and above what is contained in the food is supplied by the body itself, since as hemoglobin is destroyed the iron it contains is split off and about 85 percent is returned to the bone marrow to be used again.

Nutritional or iron-deficiency anemia results when the iron intake is low or when the iron is not properly assimilated by the body so that it does not reach the bone marrow. When the bone marrow tries to compensate for the lack of iron, the red cells emerging from the marrow become small and are low in hemoglobin. Since less hemoglobin is formed, there is a decreased amount to be broken down, so less iron is set free to be used again. Treatment consists in filling the iron hopper by providing an adequate supply of iron.

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[1] Per pound of body weight.

For a long time the accepted theory has been that the entire intestinal tract continuously regulates both the absorption of the iron into the blood stream and the excretion of the iron not needed by the body, and by so doing controls the amount of iron retained in the body. According to the theory, when the body is saturated with iron up to normal capacity any additional iron supplied should be followed by the excretion of a corresponding amount.

Recent studies have shown, however, that when the body stores of iron are complete any additional iron supplied, instead of being discarded unused, is actually retained in the body—a finding that cannot be explained by the present theory (*709, 1216*). But this and other observations can be satisfactorily explained by a new theory which holds that the capacity of the intestine to excrete iron is very limited and probably negligible, and that the amount of iron in the body is regulated by the amount absorbed (*708*). In turn, the amount of iron absorbed depends upon the amount contained in the daily diet. When the intake of iron is high, the storage organs become very active in the job of taking the iron out of the blood stream to keep the blood iron at the normal level. When the iron intake is low, the blood-iron level is kept normal at the expense of the reserve stores of iron.

Nutritional anemia may be due to other causes as well as to lack of iron in the diet or the unavailability of the food iron for use by the body. The study of iron metabolism, however, has been closely related to the study of nutritional anemia and of hemoglobin formation and regeneration. The rat, whose food habits and nutritional processes are strikingly similar to those of man (*1047*), has served as the experimental animal. A rat is fed a diet of milk—which is low in iron—with or without added copper, until its iron reserves are exhausted and the animal becomes anemic, as shown by decreased hemoglobin content. A test food containing iron is then added to the diet. The rate at which the hemoglobin is regenerated is taken as an indication of the nutritional availability of the iron in the food. Apparently the response of the anemic rat to iron depends on the basal diet used, the method of depleting the iron content of the body, and the severity of the experimentally produced anemia (*456*). The inaccuracies of the method are recognized when the values for available iron obtained in the animal laboratory are used in studies with human subjects.

DETERMINING IRON REQUIREMENTS

The amount of iron required by a normal, healthy individual is determined by placing the subject on a diet containing a known quantity of iron and finding how much iron is excreted by the body. When more iron is taken in the diet than is excreted, the body is said to be in positive balance. When the opposite occurs—that is, when the amount of iron excreted by the body is greater than the amount taken in—the body is in negative balance. The iron intake is increased or decreased until a period of equilibrium is reached when the excretion of iron is practically equal to the intake of iron. This state of equilibrium or balance implies that the body is getting all the iron that it needs for the formation of hemoglobin, but not enough to allow for any appreciable storage. The amount of iron needed just to keep the body in balance is known as the iron requirement.

To allow for physiological differences between individuals and possible fluctuations in the body's need for iron, the practice has been to average the values obtained by balance studies conducted on different subjects of the same age group and then increase the average requirement by 50 percent (*1048*). The addition of this margin of safety to the requirement gives the average daily allowance of iron. While it may approach the optimum for individuals with a requirement below or close to the average, this average daily allowance may not be sufficient to take care of the storage needs of those individuals with iron requirements very far above the average.

If there is no actual loss of blood, iron deficiency is most likely to occur when the body's demands are greatest, or during the first 2 years of life and at puberty. In women, iron deficiency may occur during pregnancy or toward the end of the reproductive period of life when more than 30 years of menstruation, punctuated by pregnancies and periods of lactation, have slowly depleted the body's store. In the presence of a diseased condition of some part of the digestive tract, an iron deficiency may occur, owing to poor absorption of the iron from the intestine. Any chronic infection, although it cannot of itself produce iron deficiency, undoubtedly interferes with the utilization of the element by the bone marrow. The purpose of supplying an adequate amount of iron in the diet every day is to keep the body supplied with more than enough iron for hemoglobin formation so that the iron stores will remain full. When the iron reserves of the body are exhausted it is very difficult to replenish them in a reasonable length of time from food sources.

IRON REQUIREMENTS

Infants

Whether or not an infant develops anemia depends upon the amount of iron stored in its liver before birth and the length of the period during which milk is the sole article of the diet. At birth the hemoglobin content of the blood is high, 20 grams or more per 100 cubic centimeters of blood. The level of hemoglobin rapidly decreases to about 14.5 grams, at the second to fourth week of life. This is not the result of an iron deficiency but is attributed to the sudden rise in the oxygen content of the blood and the resulting break-down of red blood cells when the lungs take the place of the placenta as a medium for supplying oxygen. The hemoglobin level continues to fall until about the third month of life, sometimes reaching remarkably low levels in babies of low birth weight and in premature babies. Between the third and sixth months, when the iron stored in the liver is being released, the hemoglobin level rises slightly. During the rest of the first year and the first half of the second year the level falls very gradually to about 12.5 grams per 100 cubic centimeters of blood.

Anemia caused by an insufficient intake of iron may appear at about the sixth month, when the stored iron is exhausted, or it may be delayed until about the twenty-fourth month, the end of the critical period when rapid growth makes the heaviest demand on the available iron. During this period the iron intake, particularly in the bottle-fed infant, is often infinitesimal, and if the child has entered the world insufficiently endowed with iron, anemia is certain to result. There are three possible causes for a poor supply: (1) Premature birth, before sufficient iron has been stored; (2) sharing of the available iron by twins; and (3) an anemic mother, who cannot supply the infant with enough iron.

From the few balance studies made, in which the quantity of iron retained in the infant's body has been determined by calculating the difference between the iron eaten in food and the iron excreted, it would seem that some iron-rich foods should be added to the diet well before the sixth month. A recommended regime that insures an adequate supply of iron for infants maintained on a cow's milk diet is to add orange juice and cod-liver oil before the end of the second week; egg yolk at 3 months; cereal at 4 months; broth, vegetable puree, and stewed fruit at 4 to 5 months; and scraped beef and liver at 6 months. Aside from the advantage of gradually accustoming the infant to new foods, the addition of these supplements to the diet at earlier ages than has been the practice in the past is important from the standpoint not only of the infant's requirement for iron but also his need for the other essential nutrients. In addition to iron, the orange juice supplies the vitamin C that is lacking in boiled or pasteurized cow's milk; egg yolk and liver supplement the vitamin A contained in the daily dose of cod-liver oil and are good sources of vitamin B_1 and of high-quality protein; and the whole-grain cereals provide vitamin B_1 as well as fuel value. Vegetables such as peas, carrots, and string beans, and fruits such as apricots and prunes are good sources of all the minerals, provide new textures and flavors, and increase the bulk in the diet.

The average daily iron requirement, as determined by balance studies on 15 infants, is about 0.24 milligram per pound of body weight (*870*, *1101*). Adding the conventional 50 percent for a margin of safety places the average daily allowance at about 0.36 milligram per pound of body weight.

A healthy 6-month-old infant weighing 14 pounds has a daily iron allowance of about 5 milligrams. The 28 ounces of milk in the daily diet contain about 2 milligrams, one egg yolk contains about 1 milligram, and 1 tablespoonful of ground calves' liver another milligram of iron, all in a readily available form. Six tablespoonsfuls of whole-grain cereal contain about 0.7 milligram of iron, and 0.3 milligram is contained in 4 tablespoonfuls of orange juice, 1 of apricot pulp, and 2 teaspoonfuls of pureed green peas. All of the iron in apricots is in an available form, as is over 95 percent of that in whole-grain cereal, and 75 percent in peas and orange juice. The total iron content of this sample diet for a 6-month-old infant is about 5 milligrams. To increase the iron intake to 6 to 9 milligrams, as has been proposed by one authority (*1101*), would mean increasing the size of the servings of liver and egg yolk.

A year-old infant weighing 22 pounds has an iron allowance of about

8 milligrams. The daily quart of milk supplies about 2.3 milligrams, a 3-tablespoonful serving of calves' liver adds about 3 milligrams, and an egg yolk 1 milligram. About 2 tablespoonfuls of baked potato, 1 of prune pulp, 4 of pureed peas, and about one-half cupful of orange juice supply between 1.5 and 2 milligrams, and one-half cupful of cereal adds 1 milligram, making a total iron content of about 9 milligrams. If a serving of scraped beef replaces the liver, the total iron content of the diet will be reduced by about 2 milligrams, and the available iron content will also be lower, since only about 25 percent of the iron in beef is in an available form. Practically all of the iron in potato is available, as is 75 percent of that in prunes.

Children

The years between 1 and 6 are often spoken of as the "neglected age," for during this period the child is becoming more independent, and the parents tend to assume less responsibility for his diet. The high standards of nutrition established during the first year should be maintained, for although the increase in size is relatively great during the first year of life, the infant's weight at the end of that time is only about one-sixth that of the adult, and the rest of the growth period is equally important for building body tissue.

Comparatively few balance studies have been made to determine the mineral needs of children. Until recently, the daily allowance for iron, based on comparison with the adult allowance, was 0.5 milligram per 100 calories of food.

Balance studies on 15 children of preschool age by three groups of investigators have shown that the present allowance is too low to permit optimum storage of iron (*36*, *259*, *985*). These workers are in fairly close agreement that the iron requirement is about 0.18 milligram per pound of body weight. Adding the 50 percent for a margin of safety places the average daily allowance for children between 2½ and 6 years of age at about 0.27 milligram per pound.

Another group of workers has proposed the equivalent of 0.14 milligram of iron per pound of body weight as being adequate to meet the needs of maintenance and growth of children between 3 and 5 years of age (*674*). The study was made on four children who were receiving, during the experimental period, a diet of different composition from those used in the other studies. It is possible that the availability of the iron in the diets may account, in part, for the differences in iron metabolism reported by various investigators.

In the absence of any balance experiments on children between 1 and 2½ years of age, it may be assumed that the iron allowance decreases gradually from the standard of 0.36 milligram for infants under 1 year to that of 0.27 milligram for children of 2½ years. The widespread prevalence of border-line nutritional anemia among children in the age group from 6 months to 2 years serves as a warning that the iron content of the diet must be maintained at a high level and, for some children, needs to be supplemented by medicinal iron to forestall the development of the infectious diseases to which the anemic child is particularly susceptible.

A healthy 2-year-old child weighing 27 pounds apparently needs about 8 to 9 milligrams of iron a day, while the 5-year-old child weighing 38 pounds should have about 10 milligrams a day. As a child's food needs increase with increasing body size and as the digestive tract becomes stronger, new foods that were not included during the first year are gradually introduced. The iron needs of the preschool child will be well taken care of if the iron-rich foods already an important part of the diet are continued in larger servings, and if among the new foods added to the diet are whole-wheat bread; vegetables such as cauliflower, beets, string beans, carrots, and lettuce; fruits such as apples, bananas, peaches, raisins, and dates; and chicken and lamb.

The iron requirements of older children—those between 6 and 17 years of age—have not been determined by the balance method. As a guide in planning adequate diets the practice has been to assume that the growing child needs almost as much iron as the adult man. From a number of survey studies on the health and nutritional status of children it appears that iron-deficiency anemia is seldom present in children between 5 and 12 years of age. Until further information is obtained the daily allowance for children from 5 to 11 years of age should probably be close to 9 to 11 milligrams. For boys between 11 and 17 years it should be about 13 milligrams.

Although chlorosis is often spoken of as "a disease which has accompanied tight-lacing into the limbo of forgotten things," the condition is still seen at times in adolescent girls, only it is now diagnosed as hypochromic anemia, characterized by a normal number of red cells but a reduction in the hemoglobin content of the cells. The combination of rapid growth with the establishment of menstruation may lead to iron deficiency, especially if the iron intake during earlier childhood has been consistently below the optimum allowance. Girls between the ages of 11 and 14 years are undergoing a period of acceleration in growth with increased metabolism and need a high intake of iron, probably from 13 to 15 milligrams a day.

Many children, while they may not be actually anemic, are often listless, lacking in vitality, and have a very poor appetite. These are definite signs that the body's reserve store of iron is low and is not being replenished because the available iron content of the diet is about equal to the amount needed for the formation of hemoglobin, with no surplus for storage. A sudden spurt of growth, such as may occur during the adolescent period, or an infectious disease, which progresses rapidly when the resistance is lowered, may so deplete the body of its reserve iron that anemia will result.

The problem of meeting a child's increasing need for iron cannot safely be left to chance. The mothers of a generation or so ago may not have known just why it worked, but they did recognize that a dose of sulfur and molasses in the spring was an easy way of curing listlessness in children, and even today there may still be some mothers who give pale, anemic children rusty water to drink. But the wise modern mother plans meals that contain sufficient iron each day as a means of preventing the anemic condition from appearing.

The healthy child who drinks a quart of milk and eats an egg every day is getting about 3.5 milligrams of available iron. A bowl of breakfast cereal and two slices of bread, if made from the whole grains, will supply about 2.3 milligrams of iron, practically all of which is in an available form. A slice of calves' liver 3 by 2 inches and a quarter of an inch thick will supply over 6 milligrams of available iron. These five foods would more than take care of the iron requirement of the average child under 11 years of age if they were included in the diet every day.

But calves' liver is an expensive food and not one that is desired every day. Beef liver, which is cheaper, contains only half as much iron. An egg a day is recommended by nutritionists, but few children get a whole egg a day. In place of liver, a slice of roast beef or lamb (4 by 2 by ¼ inches) will provide about 3.5 milligrams of total iron, but less than 1 milligram of available iron. Oysters, shrimp, and clams are about twice as rich in available iron as beef and lamb, while fish such as cod, perch, and trout are a poorer source. A medium-sized baked potato, servings of cauliflower, string beans, and tomato juice, and a large apple will supply over 3.5 milligrams of iron, of which less than 3 are in an available form. Small amounts of iron will be obtained from foods such as molasses, nuts, raisins, dates, figs, and chocolate, as well as from the other fruits and vegetables that may appear quite frequently in a child's diet. So the child who eats the essential foods—milk, eggs, meat, potato, two or three servings of fruits and two or three of vegetables, and some whole-grain breads or cereals every day—is sure of getting the necessary amount of iron as well as the other nutrients—protein, copper, and vitamin C—which help the iron in the important job of keeping an optimum supply of red cells and hemoglobin in the blood.

Men

Some years ago, on the basis of very few studies, 15 milligrams of iron was recommended as the daily allowance for an average man. In 1938 the allowance was lowered to 12 milligrams for both men and women (*1048*). The Technical Commission on Nutrition of the League of Nations recommends 10 milligrams of iron as the daily allowance for the adult man. Including the earlier work, much of which is now criticized on the grounds that the experimental periods lasted only 3 to 5 days and the methods used for estimating iron were inaccurate, iron-balance studies have been made on 19 adult men (*1048*). The amount of food iron required to maintain the body in iron balance, according to these studies, varies from 3.7 to 12.6 milligrams a day. Taking the average value, 8.2 milligrams, and adding 50 percent for a margin of safety, the allowance of iron for the average healthy man would be 12.3 milligrams.

Most men eat more food than do most women, and particularly the protein foods such as meat and eggs, which are good sources of iron. In the dietary studies in which the food intake of each member of the family is estimated from the approximate figures obtained for the quantities of food purchased, the men apparently get from about 8 to more than 18 milligrams of iron a day; even in the lowest income groups, the average is about 11 milligrams. Apparently men regularly take a relatively large quantity of iron, in spite of the fact that they rarely have anemia except when it is secondary to blood loss, severe infection, or organic or malignant disease.

In a recent study the diets of 63 men during a period of 1 week were carefully weighed and the iron content was calculated from food tables (*1215*). The intakes ranged from 7.8 to 28.5 milligrams of iron a day and averaged 16.8. None of the men showed any evidence of anemia regardless of the iron intake. When large doses of iron were given to about one-fourth of the group, the hemoglobin values remained practically unchanged. Apparently the men were already getting sufficient iron to allow for optimal storage, and additional amounts of the mineral were not needed. The daily allowance of iron for the average man is probably somewhere within the range of about 12 to 15 milligrams.

The iron allowance for the normal, healthy man will be more than met by larger servings of the iron-containing foods recommended for the growing child, with a pint in place of a quart of milk a day.

Women

The scarcity of research on the quantitative metabolism of iron in normal women may be attributed not only to the difficulties of analysis of iron in biological materials and the small amount of iron used by the human body, but also to the variations in the physiological state of women due to the menstrual process. It may be normal for a woman to be in negative balance during the time of menstruation and in positive balance at some other time to compensate for the loss or to prepare for the next loss. For this reason the information gained from a consideration of the results of many iron-balance studies must be considered of questionable value, since very short balance periods were used and, in most cases, the intermenstrual period only was chosen. Obviously, such investigations should be conducted over a period of time which would include all of the changes related to the menstrual process. The many difficulties encountered in studies to determine the iron requirements of women have been discussed in a recent paper by the author (*277*).

From the data obtained in the balance studies and from blood tests made on supposedly normal women, many investigators are reporting values for the hemoglobin content of the blood. The values are, in general, within the range of about 12 to 14.5 grams of hemoglobin in 100 cubic centimeters of blood. The variations in the values may be attributed to differences in methods of determination, the effects of exercise and of day-to-day variations, and the influence of the menstrual cycle, as well as to dietary deficiencies. Altitude and climate may also be contributory factors.

During the past 25 years the normal hemoglobin standard for women has been set as low as 12.96 and as high as 15.53 grams per 100 cubic centimeters of blood. For some time it has been accepted that the average percentage of hemoglobin in the blood of normal healthy men is about 10 percent above that of the average value for normal women. In view of definite evidence that it is comparatively easy to raise the level of hemoglobin of women about 10 percent by giving additional iron, while this is not the case with men (*1215*), the question is raised as to whether the accepted "normal" for women is the true normal or should be regarded as a subnormal value.

There is also the possibility that some of the women who served as subjects in the studies to establish a standard value for the hemoglobin level may have had unsatisfactory nutritional backgrounds, which would tend to lower the hemoglobin average of the whole group. Very few investigators offer any explanation concerning the selection of subjects other than to record that they "were known to be normal and nonanemic," "showed no evidences of dietary deficiencies," "were normal and healthy," or had passed a medical examination within a year before the study was undertaken. In the absence of satisfactory standards for judging the nutritional status of an individual, it is probable that many of the women subjects were in a state of merely passable health. Until a clear distinction can be made between those who are enjoying buoyant health and those in a state of merely passable health, it will not be possible to establish the optimal hemoglobin level for women.

The average woman has a caloric intake about 800 calories below that of the average man. Therefore, on the same type of diet, the amount of iron taken by a woman would naturally be lower. That such is usually the case has been shown in various dietary studies, and particularly in a recent one (*1215*) in which the iron intakes of 63 women were compared with those of 63 men. The women had an average iron intake of 11.4 milligrams, which was only 68 percent of the men's average intake. The highest value found for any woman was just above the average for the men. The minimum intake was 5.5 milligrams, with almost 30 percent taking less than 10 milligrams a day.

The lower iron intakes of the women are attributed to their more restricted intakes of all foods and, particularly meat, of which they ate only about 3 ounces a day, while the men ate about 5.2 ounces. However, the women evidently preferred the fruits and vegetables, eggs, and milk products, in which practically all the iron is in an available form, for the average intake of available iron was 7.9 milligrams a day, or about 76 percent of the total iron intake. The content of available iron in the men's diets was higher, 10 milligrams, but it represented only 64 percent of the total iron intake, since meat, except such organs as liver and kidney, is very low in available iron.

One of the most interesting findings in the study was that the women, with lower intakes of iron, had hemoglobin values averaging about 9 percent below those of the men subjects. When large doses of iron were given each day for about 2 weeks, the hemoglobin levels increased from 12.8 to 14.1 grams in 100 cubic centimeters of blood, whereas the value for the men subjects remained within about 1 percent of the original 14.2-gram level. It is evident that the level of hemoglobin in normal women's blood is limited as well as regulated by their intake of iron. The prevalence of hypochromic anemia among women can be attributed to their low iron intake. Men, with an iron requirement obviously less than that of women, apparently get more iron than they need, while women appear to get less than they need for normal functioning of the body processes.

The results of a recent clinical study suggest that a relationship may exist between the utilization of iron in woman's body and the action of one or more hormones produced in the glands of internal secretion (*1031*). A group of anemic women who failed to respond to treatment with iron showed definite improvement when extracts from the thyroid, ovarian, and anterior pituitary glands were given with the iron. While no definite conclusions have been drawn from the preliminary study, there is evidence that a condition of iron deficiency may persist even when the iron intake is adequate if a glandular disorder is present which interferes with the proper utilization of the iron by the body. The presence of some biologic factor in the body which evidently determines the amount of iron removed during each menstrual period is suggested by the reports of studies such as one (*61*) in which the quantity of iron lost in this way by 50 women varied from 3.84 to 78.4 milligrams.

Iron-balance studies have been made for 3 to 14 days during the intermenstrual period on 10 women (*357*, *709*, *1161*, *1216*) and during consecutive menstrual cycles over 3 to 5 months on 4 other women of child-bearing age (*683*). The amount of iron required each day to maintain the body in equilibrium varied from 5.2 to 8.3 milligrams and averaged 6.4 milligrams for the women subjects of the studies in which the complete menstrual cycle was not considered. The amount of iron required by the 4 women through all phases of the menstrual cycle was considerably higher and varied from 10.83 to 13.61 milligrams, with an average value of 12 a day. Adding to the average requirement the 50 percent for the margin of safety would place the average allowance of iron for women of the childbearing period at 9.6 milligrams if the results of the short balance tests are accepted, and 18 milligrams on the basis of the findings of the longer tests.

A number of workers engaged in iron-metabolism studies have advocated that the iron allowance for women should be raised to 17 to 20 milligrams rather than lowered to 12 as has been proposed. The author of one report (*793*) believes that "women require about four times as much iron as men up to the time of the menopause." Whether or not the iron requirement is as high as that, it would seem that there is enough of the newer knowledge of nutrition sufficiently established to justify the conclusion that normal, healthy women during the childbearing period need at least 17 milligrams of iron a day.

In middle age when the iron stores of the body are no longer taxed by the reproductive processes, the iron requirement of women is lower. For the maintenance of health and vitality with advancing years, an iron allowance of 12 to 15 milligrams is probably adequate.

To obtain about 15 milligrams of iron, the foods eaten each day should include a pint of milk, one egg, a serving of whole-grain cereal and two slices of whole-wheat bread, a serving of meat or fish and one of a cooked dried fruit such as peaches, prunes, or apricots, an orange and another fresh fruit such as apple or banana, and servings of potato and two other vegetables such as cabbage and carrots. A generous serving of liver, kidney, or heart should be added to the diet at least once a week.

To get an additional 2 milligrams of iron, the amount of egg yolk should be increased and the liver or other organs taken twice a week, with a serving of bacon or ham added occasionally. In addition to more generous amounts of raw fruits and vegetables, the diet should include salads and desserts containing raisins, dates, figs, or nuts. Other foods that are good sources of iron are dried navy beans, lima beans, and soybeans, dried lentils, black-eyed peas, rhubarb, dandelion and mustard greens, molasses, cocoa, and chocolate.

Pregnant and Nursing Women

In the White House Conference report (*1210*) the iron content of the newborn infant is given as 375 milligrams, all of which is obtained by transfer from the mother. It amounts to about 0.4 milligram a day during the first two-thirds of pregnancy and 4.7 milligrams a day during the last third. In pregnancy, therefore, the daily iron intake should be increased by at least 3 milligrams to take care of the needs of mother and child and allow for storage by the infant of iron that will be used during the first few months of life.

When the intake averaged about 15 milligrams a day, 15 pregnant women were getting just about enough iron for their own needs and those of the developing infant, but not sufficient to allow for any margin of safety (*221*). The frequent occurrence of hypochromic anemia during the latter part of the pregnancy period is evidence that the iron intake is too often close to the border-line requirement without any consideration for the safety factor. For that reason 20 milligrams of iron a day has been proposed (*739*) as a desirable allowance during pregnancy.

Iron-deficiency anemia is almost as common among nursing women as it is during pregnancy, although the nursing woman supplies the infant with less than 1 milligram of iron a day in the breast milk, so that the iron taken in the food is practically all used to meet the needs of the mother's body. The iron requirement of the nursing woman has not been determined by the balance method as yet. Until experimental data are available it may be assumed that the nursing woman requires more iron than does the nonnursing woman, but perhaps not quite as much as during the pregnancy period. To be sure of an allowance of 17 to 20 milligrams of iron a day, such foods as liver, kidney, and other meats, eggs, whole-grain cereals, fruits, and green vegetables, which are such an important part of the diet during pregnancy, should be eaten in ample amounts during the nursing period also.

COPPER

A copper deficiency is rarely found in human beings. The infant is born with a reserve supply of copper for use in the formation of red blood cells and hemoglobin, but these stores need to be refilled by the addition of copper-containing foods to the milk diet during the first few months of life.

Fortunately, the best sources of copper are the iron-containing foods. In general, foods that will supply 4 to 5 milligrams of iron will also supply about 1 milligram of available copper. The chief difference between the distribution of iron and copper in foods is that poultry is superior to beef in copper content. Iron and copper are about equal in the leafy vegetables, legumes, and root vegetables. Liver, oysters, molasses, chocolate, and cocoa are outstandingly high in copper as well as in iron content.

The copper requirements of human beings have been determined by experiment for adults only. Since iron and copper occur together in foods in such amounts that it is not possible to meet the iron requirement without supplying sufficient copper for the average healthy individual, it is suggested that the amount of copper contained in a diet that meets the recommended allowance for iron may be taken as representing the copper allowance.

The daily allowances of copper discussed in this paper may be summed up as follows (in each case it is assumed that the individual is normal and healthy):

	Milligrams		*Milligrams*
Infant	1–1. 5	Woman	3. 5
Child	1. 5–2. 5	Pregnant woman	3. 5 4
Man	3. 5	Nursing woman	3. 5–4

FUNCTION OF COPPER IN THE BODY

Although copper is not a constituent of hemoglobin, it is one of the most important factors in the utilization of iron for the formation of hemoglobin. Copper is present in varying amounts in all living matter, indicating that it is essential for both plant and animal life. The copper present in the human body, estimated at 100 to 150 milligrams, or 0.10 to 0.15 gram, is almost all contained in the muscles, bones, and liver, with only a small amount—less than 4 milligrams—present in the blood (*204*).

What controls the copper content of the blood is not known, but it has been observed in some species of animals that the blood copper is markedly decreased in nutritional anemia (*1017*). When anemia threatens the body is apparently able to call upon its reserve stores of copper to raise the content in the blood in an effort to speed up the formation of hemoglobin and of red blood cells. When the body stores have been depleted, the copper may almost disappear from the blood unless additional copper is given. The animal will then be in a state of copper deficiency and will have all the usual symptoms of anemia. Since the animal body is not able to form red blood cells and hemoglobin in the absence of copper, or at best can form them only at a very slow rate, both iron and copper must be administered before the anemia will be cured.

That the rat requires a trace of copper for the formation of hemoglobin has been established (*493*). The difficulty of completely removing the copper from iron salts and from foods has been suggested as the reason why some investigators have been unable to confirm the finding.

In view of the similarity between the nutritional anemias of infants and of young animals, the use of copper together with iron in the treatment of anemic infants has been tested by various workers. Some of the reports (*326*, *600*) show that anemic infants so treated have a more rapid increase in hemoglobin formation than do others receiving iron alone. One investigator (*897*) is of the opinion that copper may be of value in certain cases, since a few of the anemic infants in his study failed to make a complete recovery until copper had been added to the iron supplement. Others believe (*730*) that if adequate doses of iron are given, copper is not necessary.

For the treatment of women with hypochromic anemia there appears to be no consistent advantage in the administration of copper and iron over that of iron alone, indicating that a deficiency of copper is rare among women (*284*).

DETERMINING COPPER REQUIREMENTS

The amount of copper needed by a normal, healthy individual is determined by the balance method, as in the case of iron. The test periods are from 3 to 7 days, and the copper intake is changed until a period of equilibrium is reached when the copper excreted by the body about equals the copper taken in. So far, this has been done only for adults.

COPPER REQUIREMENTS

Infants and Children

The copper content of the infant's liver just before birth is about 10 times and after birth about twice (*244*) that of the adult liver. Just as food iron is supplied very early in life in anticipation of the time when the high liver-iron stores which the infant possessed at birth will be exhausted, so must copper be supplied to keep the copper stores at the optimal level.

The sources of readily available copper in the infant's diet are the iron-containing foods—liver, egg yolk, whole-grain cereals, fruits, and vegetables. Although cow's milk is almost devoid of copper, some is added in the pasteurization process when the milk is passed over heated copper rollers, or when copper cooking utensils are used.

A healthy 6-month-old infant on a diet that contains about 5 milligrams of iron will also be getting more than 1 milligram of copper. The larger servings of the iron-rich foods in the diet of a year-old infant supply about 1.5 milligrams of copper.

The diet of the preschool child contains the foods added during the first year of life and other foods such as whole-wheat bread, lettuce, cauliflower, cabbage, beets, apples, raisins, dates, chicken, and lamb—all of which contain appreciable amounts of copper. Among the foods that may be added to supply the additional copper needed by older children are molasses, nuts, currants, shellfish, and other fish. The copper content of oysters is so high that one large oyster will supply about 0.5 milligram of copper. From 1.5 to almost 3 milligrams of copper are contained in a well-planned diet that supplies from about 8 to 13 milligrams of iron.

Until the requirements for infants and children have been determined by experiment, the daily copper allowance for the infant may be tentatively set at 1 to 1.5 milligrams, and for the growing child at 1.5 to 2.5.

Men

From copper-balance experiments conducted on three men by a group of Chinese investigators, the daily copper requirement for the average man was estimated to be 2.4 milligrams (*204*). The addition of 50 percent for a margin of safety places the daily copper allowance for men at 3.6 milligrams. The foods that supply 12 to 15 milligrams of iron also contain about 3 milligrams of readily available copper.

A comparison of the copper requirement with that for iron, 8.2 milligrams, gives a ratio between the two of 1 part of copper to 3.4 parts of iron.

Women

For the average woman the copper requirement is 2.5 milligrams, according to the results of balance experiments conducted on 23 normal, healthy women of childbearing age.[7] The addition of 50 percent for a margin of safety would make the daily copper allowance for the average woman about the same as that for the man, 3.7 milligrams.

A comparison of the copper and iron requirements of the woman gives a ratio of 1 part of copper to 4.8 parts of iron. It may be that further studies will either lower the present copper requirement for men or will show why men, with a lower iron requirement, should have a copper requirement equal to that of women. For the present, the copper allowance of the adult—man and woman—may be set at 3.5 milligrams.

PREGNANT AND NURSING WOMEN

Very little information is available regarding the need for copper during the pregnancy and nursing periods. It is known, however, that the infant stores copper during uterine life and that the blood-copper level of the pregnant woman increases during the latter part of pregnancy from a normal of 0.18 to 0.23 milligram to 0.2 to 0.35 milligram per 100 cubic centimeters of blood. The increase in blood copper is associated with active blood formation in the mother and the infant's demands for copper. It is of interest that the blood-copper level is raised even in pregnant women who are anemic.

The copper allowance for the pregnant woman, for whom the iron allowance is about 3 milligrams above that of the nonpregnant woman, is probably between 3.5 and 4 milligrams a day. For the nursing woman, the daily copper allowance would also be within the range of 3.5 to 4 milligrams.

Some of the diet surveys that have been made on groups of families in different parts of the world show that even the very poorest families are eating foods that supply at least 2 to 3 milligrams of copper a day (*265, 876*). Any diet that contains about 12 milligrams of iron will supply about 3 milligrams of copper. As additional iron-containing foods are included, the copper content of the diet will be automatically increased about 1 milligram for each addition of 4 to 5 milligrams of food iron.

IODINE AND FLUORINE

by Margaret Cammack Smith[8]

THE two chemically related mineral elements, iodine and fluorine, differ greatly in nutritional significance. Iodine is an essential constituent of the thyroid gland, necessary for the formation of thyroxin, which regulates basal energy metabolism and growth. Fluorine, on the other hand, cannot be considered an essential element of the human body. Its presence in the body is probably due to its occurrence in the food supply. Because of its chemical affinity for calcium, it is deposited in the bones and teeth in variable amounts in combination with calcium, but it is without known physiological function.

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[7] LEVERTON, R. M. COPPER METABOLISM OF 23 WOMEN. Personal communication from the author.

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IODINE

Lack of iodine in the water and food supply is considered the chief if not the only cause of simple goiter. In the so-called goiter belt, which stretches along the Appalachian Mountains as far north as Vermont, westward through the basin of the Great Lakes to Washington, and southward over the Rocky Mountains and Pacific States, the incidence of goiter is high.

Most of our knowledge concerning the human requirement for iodine is based on estimates of the iodine intake and excretion of people in nongoitrous and goitrous regions and on attempts to prevent goiter in the latter. The problem is complicated by the fact that iodine can be stored in relatively large amounts in the body. However, a probable human requirement (*955*) has been estimated to lie between 0.05 and 0.1 milligram a day, with the higher amount indicated during childhood and again for women during pregnancy and lactation.

Sea foods are all rich in iodine, but it has been repeatedly shown that the iodine content of plant foods and of the water supply (*718*) is subject to great variation, the same food being relatively high in iodine in nongoitrous regions and low in regions where goiter is prevalent. For this reason prevention of goiter in goitrous regions is largely a matter of not depending upon the ordinary food and water supply for iodine but employing other methods to increase the iodine intake. The use of iodized salt in the proportion of 1 part of iodine to 100,000 parts of salt has received the approval of the American Medical Association and is generally accepted as the best method of reaching the largest number of people who need iodine medication. Criticism of the continuous use of iodized salt has centered around a possible abnormal excitation of thyroid-gland function. It has been pointed out (*720*) that the danger of a toxic effect from iodized salt can be minimized if its use is limited to the first 20 or 30 years of life and periods of pregnancy and lactation.

Under active investigation at the present time are methods of increasing the iodine content of man's food supply by adding it to fertilizers used in growing plant foods (*729*) and enriching the diet of the dairy cow (*956*) and the egg-laying hen (*41*) by feeding iodine concentrate. Results show that such enrichment is possible, the extent of increase in iodine content of the food being dependent upon the amount and kind of the iodine compound used.

FLUORINE

In contrast to the tendency to iodine deficiency, too much fluorine in the water supply is detrimental. Fluorine has been shown to be the cause of a disfiguring dental disease known as mottled enamel or fluorosis (*1077*). Fluorine interferes with the normal calcification of the teeth during the process of their formation, so that affected teeth, in addition to being usually discolored and ugly in appearance, are structurally weak and deteriorate early in life. For this reason, it is especially important that fluorine be avoided during the period of tooth formation, that is, from birth to the age of 12 years.

Fortunately most of our large city water supplies do not contain toxic concentrations of fluorine, but there are sections in Arizona, California, Colorado, Florida, Idaho, Iowa, Kansas, Minnesota, Mississippi, Montana, Nebraska, New Mexico, North Dakota, South Dakota, Ohio, Oregon, Texas, Utah, Wisconsin, Wyoming, Africa, Canada, China, England, Italy, New Zealand, and South America in which all native-born inhabitants who have used the community water supply during the period of enamel formation have mottled teeth.

Quantitative knowledge of the human requirement for iodine and the human tolerance for fluorine has been handicapped by the minuteness of the amount involved in each case, which causes difficulty in analysis and measurement.

Correlation studies (*1070*) between the occurrence of mottled enamel and the fluorine concentration of the water consumed by afflicted persons show that this dental disease is always found when water containing even as little as 1 part per million of fluorine is used continuously during the period of formation of the permanent teeth. Severe mottling of the temporary teeth (*1078*) has been repeatedly observed when the fluorine concentration of the water is excessively high (6 to 16 parts per million). Water containing such high concentrations of fluorine cannot be safely used even for cooking.

The fluorine content of foodstuffs has been found to vary widely, but no evidence has been advanced so far to show that fluorine as combined naturally in foods is toxic. The fluorine problem therefore is chiefly concerned with the need for avoiding water containing fluorine in order to prevent the occurrence of mottled enamel. In many communities this is difficult, for all available water is contaminated with fluorine. In the past few years several methods of treatment of water for the removal of fluorine have been investigated, most of them proving unsatisfactory. The Arizona Agricultural Experiment Station has recently developed a method (*1069*) of fluorine removal by filtration, through the use of specially prepared ground bone, which has proved effective and practical for reducing the concentration of fluorine below the level that causes the dental disease. The method is based upon the previously mentioned fact that fluorine has a chemical affinity for the calcium of bone.

The use of fluorine compounds as spray insecticides (*1079*) for vegetables and fruits presents another problem. Tests on rats indicate that the compounds of fluorine studied were equal in toxicity and that cryolite, a fluorine compound commonly used as a spray insecticide, was just as effective as the more soluble fluorine compounds in producing mild mottled enamel. Government control of the use of these compounds is recommended as a means of prevention of fluorosis, although the question of exact tolerance level for fluorine spray residues on food materials merits further investigation.

TRACE ELEMENTS

by Esther Peterson Daniel[9]

When plant or animal material is burned, the bulk of it disappears into the surrounding air as water and carbon dioxide, leaving a small amount of ash. Chemists can find out what minerals are in this remaining ash by photographing the light given off when a small amount of it is heated to incandescence in an electric arc. For years it has been known that under certain conditions of heating each chemical element sends out its own particular light waves, which are never shown by any other element. Pictures of these light patterns, made by means of an instrument known as the spectrograph (fig. 2), show what individual elements are in a substance. In the past this method was used chiefly by engineers to study alloys and to detect impurities in various metals. More recently the spectrograph has been used to discover new things about living matter, both plant and animal.

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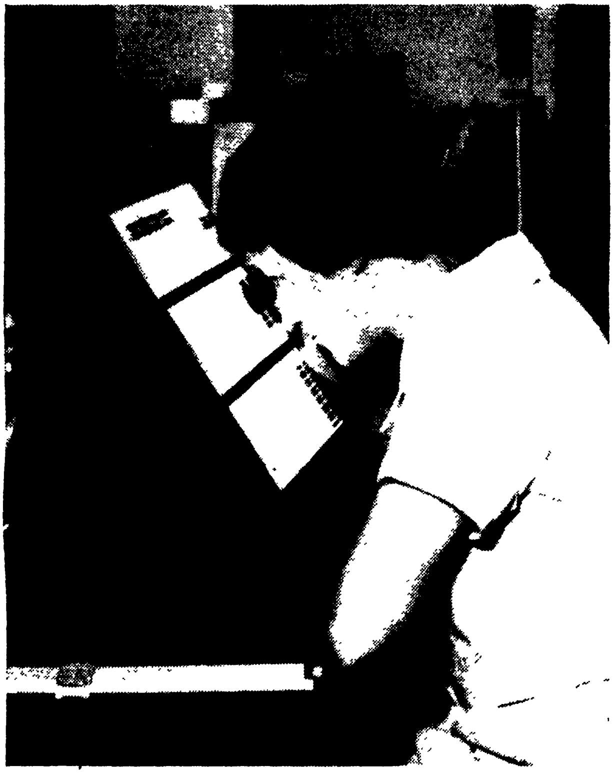

Figure 2.—Examining the fine lines of a spectrogram (the picture taken with a spectrograph) as a means of detecting the trace elements present in foods. The quantities are so small that they had been completely overlooked in other methods of analysis.

By this method it was learned that certain chemical elements occurring in foods in mere traces—quantities so small that they had been completely overlooked—were tremendously important. Plants and animals attempting to live on foods lacking in these elements are stunted and deformed, or unable to live at all. On the other hand, just a little too much of these so-called trace elements may prove equally disastrous to the health and life of the plant or animai.

Soon scientists (*142*, *509*, *981*, *1034*, *1195*, *1233*)[10] were eagerly searching to find which of the chemical elements had such powerful influences and what they did in the body to make them so necessary. These questions have been far better answered for plants than for animals or men. Many of the common diseases long a menace to farm crops are now known to be due to improper amounts of one or another of these trace elements. Careful observations of small animals kept in the laboratory on experimental diets, as well as of various kinds of farm animals, have given many interesting glimpses regarding the effects of trace elements in the animal kingdom. Much still remains to be learned regarding the effects of these elements in the life of man, whose habits and environment are so much more complex and difficult to study. This portion of the story is just beginning, as will be readily recognized from the following brief review of the meager information now available regarding certain of these trace elements in human nutrition. There is no doubt, however, of the tremendous nutritional significance of some of them.

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[10] Also: AMERICAN PUBLIC HEALTH ASSOCIATION. MINERAL ELEMENTS IN NUTRITION. Amer. Pub. Health Assoc., Com. on Nutritional Problems Rept., 14 pp. 1936. [Mimeographed.]

MANGANESE

Traces of manganese may be found in water, plants, and animals. Many amethyst-colored minerals owe their delicate hue to this element. From the time of the ancient Egyptians it has been used for bleaching glass, and today it is used, among other ways, in the manufacture of special steel, in the paint industry, and as a depolarizer in dry batteries.

It appears that manganese in very small quantities is necessary in the human diet, although its particular action in the body is not yet known. The greatest amounts have been found in the liver, pancreas (the corresponding gland is commonly referred to as sweetbread in animals used for meat), and suprarenals (small glands located just above the kidneys, which provide substances important in certain regulatory processes in the body). Experimental rats deprived of manganese show sterility in the males and lack of maternal instinct in the females. During pregnancy manganese passes into the blood stream of the unborn child, and the fecal discharge of the newborn infant contains a remarkable amount. The recent discovery that leg-bone deformity in chickens, known as perosis, is accompanied by manganese deficiency has suggested the possible necessity of this element for normal bone development. Studies indicate that as little as 1 ounce of manganese taken over a period of 12 to 15 years will furnish an adequate amount of this element for children. On the other hand, a manganese poisoning is known to occur among certain industrial workers employed in plants using considerable quantities of this element.

COBALT

For 25 years or more, a disease prevalent in both New Zealand and Australia, commonly referred to as "Coast disease," or "Morton Mains disease," has taken a great toll of sheep and cattle (*1274*). Its cause remained obscure until recently, when conditions became so desperate that an intensive study was undertaken. The facts indicated that animals on newly broken land and deep-plowed areas did better for a time. Good farmers who top-dressed their soil with lime and superphosphate to obtain a luxuriant grass growth were particularly troubled with the disease. A number of facts indicated that something was lacking in the diet of the animals. After exhaustive analyses, it was found that the soils in the stricken areas were deficient in cobalt. In consequence the feed grown on them contained little or none of this element, and the animals eating it were dying from cobalt deficiency. This was a new idea; never before had anyone dreamed that cobalt, long used to impart a lovely shade of blue to glassware, was secretly playing a much more vital role. Farmers completely eliminated the trouble by placing a little cobalt in the fertilizer or supplying salt licks containing traces of cobalt. One ounce of cobalt sulfate daily is sufficient for approximately 4,000 animals.

This element has been found in extremely small amounts in most of the organs of the human body. Cobalt is known to increase the number of red corpuscles in the blood, and there is evidence that it may be beneficial in certain types of anemia. Some persistent human nutritional anemias refuse to clear up completely with the usual iron treatment, and the partial cure effected by iron compounds in such cases is now believed to be due to the traces of cobalt which these salts have been found to carry as impurities.

ALUMINUM

Since aluminum cooking vessels have come into extensive use, considerable interest has centered about the effects of this element in the diet. Particular concern was voiced that poisoning might result from eating the extra quantities of aluminum which were dissolved out of the pan into the food. Baking powders containing this element were also questioned. Rather extensive studies have shown no evidence of aluminum poisoning from amounts in excess of those which would ordinarily be ingested. It has been estimated that on the average a human being eats approximately 1 ounce of aluminum in 6 years. About half of this occurs naturally in the foods; the remainder is dissolved from the cooking utensils. Although aluminum has been found generally distributed in varying amounts in the body, scientists are still trying to discover whether its presence is merely accidental or perhaps a necessity for the health and even the life of man.

MAGNESIUM

In 1695 a man named Grew described a magnesium salt which he found in mineral springs at Epsom as having medicinal properties.

Magnesium is a very important ingredient in chlorophyll, the green coloring matter in plants.

If the magnesium content of the diet is reduced to a very low level, a little less than two parts per million of diet, experimental animals become sick and die. The blood vessels expand, the heart beats more rapidly, the animals become irritable and finally die in convulsions. There is evidence that in some way magnesium aids in the use of fat in the diet.

There have been a few cases in which the blood of human subjects suffering from irritability have shown low values for magnesium. Normal development apparently depends upon the presence of magnesium, but our still meager knowledge concerning its action encourages further searching for the purpose of this element in human nutrition.

ZINC

For a period of more than 15 years there has been considerable interest in the possible necessity of zinc in the diet. It is always present in human tissues, the greatest concentration having been found in the sex organs and thyroid. The liver of an infant contains more than three times as much as the liver of the adult. This suggests a storage of zinc in the child before birth, as is known to occur in the case of copper and iron. Human milk, as well as that of cows and ewes, contains zinc; in each case the amount in the milk is greatest immediately after the birth of the young. For a period of 10 to 15 days there is a sharp drop in the amount of zinc found; thereafter it remains the same. After repeated attempts by several investigators, a zinc deficiency in experimental animals was finally produced in 1935. While this work demonstrated the necessity for zinc for normal development, the exact action of this element in animal nutrition still remains obscure.

TIN

Since the great use of tin in the canning industry, considerable attention has been focused on the tin content of canned foods and its ultimate effect in the body. There appears to be no danger of harmful effects to those ingesting the quantities of this metal found either in canned or natural foodstuffs. Tin has been noted in many of the human tissues; it seems to be concentrated in the suprarenal glands and occurs in considerable abundance in the liver, brain, spleen, and thyroid gland. One investigator found exceedingly large amounts of tin in the mucous membrane of the tongue, a curious fact encouraging further study.

ARSENIC

There is growing evidence that arsenic, well-known poison and valuable drug, may also prove to be an indispensable element in human nutrition. It is generally found in traces in most of the human tissues; the amounts present vary, depending upon food, water, medication, and environment. The liver appears to be the storehouse for this element; the quantities not stored are eliminated in the urine. During menstruation the amount found in the blood stream increases by 50 percent, while during the fifth and sixth months of pregnancy the concentration in the blood is three to four times the normal quantity. A similar increase is also found in cases of cancer. Here, then, is an element that seems closely associated with the physiology of man. In just what manner it acts is a question that remains unanswered.

VANADIUM

This element is generally recognized in its connection with the manufacture of vanadium steel; 0.5 percent of vanadium makes an alloy twice as strong as ordinary steel.

It has long been known that vanadium is essential to the ascadians, a low order of life in the animal kingdom. Its occurrence has been reported by earlier workers in a number of foods, including milk and eggs, but with improved methods of study it now appears that vanadium is not as widely distributed in nature as was formerly supposed. Experiments are now in progress in the Bureau of Home Economics in which the nutritional significance of vanadium is being investigated. It is not toxic to experimental animals in amounts generally considered relatively large for trace elements. Quantities up to 25 parts per million of the diet have no toxic effects, and 100 parts per million produce only very slight symptoms in experimental animals.

SELENIUM

The dramatic story of selenium in nutrition competes with that of cobalt (*827*). For years in the general area in the United States including South Dakota, Wyoming, Nebraska, and Kansas, farm animals fed on locally grown feed suffered from what was known as "alkali disease," and many died. An intensive investigation disclosed about 1932 that selenium was responsible for this condition; this time, however, the trouble was not caused by a deficiency of the element but by its poisonous effect. Wheat grown on soil containing 2 parts per million of selenium might concentrate this element to the extent of 25 parts per million in the grain, more than double the quantity needed to produce a grave poisoning in farm stock.

The recognition of this problem suggested another danger, namely, the effect of produce from home-grown gardens upon human health in the affected communities. The United States Public Health Service made analyses of many locally produced foods in the selenium-endemic regions and found that meat, eggs, milk, and vegetables are constant sources of this element in the dietaries of families living in these areas. Different forms of vegetation vary in their ability to take up selenium from the soil. For example, in such vegetables as potatoes, cucumbers, beets, tomatoes, and carrots the content of selenium is generally low, while cabbage, rutabaga, and especially onions can concentrate it to a high degree. The exact extent to which any ill health occurring in a community in the area can be ascribed to selenium is still uncertain.

BROMINE

The halogens, a group of elements consisting of fluorine, chlorine, bromine, and iodine, are all of particular interest in human physiology. Far less is known about bromine than the others of this group, which are discussed elsewhere, but its constant occurrence in blood cannot be overlooked. In certain mental conditions, known as manic-depressive psychoses, the normal blood bromine is reduced to about half and remains low until there is an improvement in the pathological condition. The bromine content of the blood is changed also during menstruation. The growth-regulating portion of the pituitary gland (a small but extremely important organ situated near the base of the brain, which has tremendous influence on many of the activities taking place inside the body) contains concentrations 7 to 10 times greater than that of any other organ. There is a considerable variation in the bromine content of the tissues with age; after 45 the amount begins to fall, and at 75 years of age only a trace, if any, remains. All of these facts suggest many important questions concerning the action of bromine which need investigating.

BORON

Boron is universally present in the plant kingdom, where it plays a part in calcium metabolism and in transporting and possibly in utilizing carbohydrate. While there is still no certain knowledge of its function in the animal kingdom, evidence strongly indicates that in exceedingly small concentrations boron may play a significant role in human nutrition.

NICKEL

Nickel has been found more widely distributed than cobalt in the human tissues and is particularly concentrated in the pancreas. Thus far nothing is known of its physiological function.

LITHIUM, RUBIDIUM, CAESIUM

There is meager knowledge regarding the alkali metals other than sodium and potassium, which occur in human tissues in relatively large amounts and have been universally recognized for years for their remarkable physiological action. Caesium is seldom found in animal tissues, although it is readily absorbed when available. Lithium is occasionally found in human tissues, but so far there is nothing known which indicates any physiological importance. Rubidium, on the other hand, is widespread, it is readily absorbed by protoplasm, and several authorities have suggested a possible biological role. It regularly occurs in human livers, the amount present being slightly greater during the nursing period. This fact, together with the fact that there is an increased concentration of rubidium in the livers of infants dying from a condition present at birth known as congenital pyloric stenosis, in which there is a constriction in the opening between the stomach and small intestine, has led to the suggestion of its possible necessity in muscle growth.

BARIUM, STRONTIUM, BERYLLIUM

Very little is known about the elements which belong to the same family group as magnesium. Both barium and strontium have been found occasionally in human tissues, and curiously enough, barium is always present in the eyes of cattle in amounts that increase with age. The significance of this finding is entirely obscure and such an observation has not been found with any other animal studied. There is no evidence that beryllium occurs naturally in living tissue, although the severe rickets produced as a result of feeding excessive amounts of this element to experimental animals is well known.

SILVER AND GOLD

The accepted importance of copper in animal nutrition, already discussed (p. 208), prompts an interest in the physiological significance of other members of this chemical family—gold and silver. Thus far there is no satisfactory demonstration of the presence of gold in living tissue, although the question is still an open one. On the other hand, silver has been reported in blood, liver, uterus, and ovaries, with traces in heart, spleen, and kidney. It is particularly concentrated in the thyroid gland and in the tonsil. It remains for future study to indicate whether its presence is merely accidental or significant.

CADMIUM, MERCURY

Cadmium, which is closely related to zinc, has not yet been reported in human tissues, and there is nothing to indicate particular interest in it from the biological viewpoint. Mercury, another member of this group of elements, has been found in the human liver and in a number of foods. Amalgam dental fillings provide a significant source of mercury for a period of 3 or 4 months after they have been inserted. Part of the ingested mercury is excreted in the feces, part in the urine. Mercury, a normal constituent of the diet, is not injurious to health in amounts ordinarily ingested, but any indication of its physiological necessity is at present lacking. One of the salts of mercury familiarly known as calomel (mercurous chloride) is often used as a cathartic. Another of its salts, corrosive sublimate (mercuric chloride), is exceedingly toxic.

SILICON, GERMANIUM, LEAD

The group of elements belonging to the same family as tin all have shown properties of physiological interest. Cases of silicosis occurring comparatively frequently among workers inhaling excessive amounts of silicon have familiarized many with this element. Next to oxygen, silicon is the most abundant element in the soil. Many human tissues contain silicon, and a compound of silica and carbohydrate has been found in urine. In plants, silicon is apparently concerned with phosphorus metabolism.

Germanium has been frequently reported to occur in blood, where it stimulates the manufacture of red blood cells, and there is evidence that it may act as an oxygen carrier. It is nonpoisonous to the animal body in relatively large doses.

There is no evidence to indicate that lead normally possesses any particular physiological function. It is even more widely distributed than tin, but investigators do not agree regarding the tissues of the body in which it normally occurs or the amounts present. On the other hand, lead poisoning resulting from excessive quantities is well known. Several cases have been traced to drinking water carried through short sections of lead pipes, from which water readily dissolves more than sufficient lead to produce severe poisoning. All children's toys, cribs, and baby carriages should be painted with special lead-free paints to avoid the all-too-frequent occurrence of lead poisoning in children.

TITANIUM, ZIRCONIUM, CERIUM, THORIUM

Titanium is another element widely distributed in nature and in human tissues, but its possible physiological significance is completely unknown. A record of the occurrence of zirconium, cerium, and thorium, other elements belonging to the same family, offers no clues regarding their biological properties.

ANTIMONY, BISMUTH, CHROMIUM, MOLYBDENUM

Concerning the occurrence of antimony and bismuth data are meager, and there is nothing to arouse especial interest.

There is considerable controversy over the occurrence of chromium and molybdenum in biological material, and until more data are available no prediction can be made regarding these elements.

VITAMIN NEEDS OF MAN

WITH dramatic rapidity, the vitamins are now being purified, definitely isolated, and even produced synthetically in the laboratory. This makes possible a much closer study of the part they play in very fundamental but obscure processes of life, as well as of their effects in preventing diseases due to inadequate diets. Here are the principal facts now known about vitamins A, B_1, C, D, and E, riboflavin, and nicotinic acid, including what is known about human requirements for these substances.

VITAMIN A

by Lela E. Booher and Elizabeth C. Callison [1]

MANY CENTURIES ago man learned that certain physical defects and diseases could be prevented or cured by eating certain articles of food. For example, eating generous amounts of the livers of animals was known by the Egyptians and Chinese as early as 1500 B. C. to improve vision in dim light. Only recently has it been learned that the vitamin A in animal livers is responsible for this improved visual adaptation in persons who have received too little of it in their diet.

It is now known that many foods contain vitamin A or its precursors, and knowledge of the functions of this dietary essential in the body is gradually being accumulated.

DISCOVERY OF VITAMIN A

About 30 years ago the first attempts were made to rear young animals on mixtures of purified proteins, lard, starch, and salts in place of mixtures of natural foods. These experiments soon ended in a complete failure of growth followed by untimely death of the animals. Additions of skim milk or whey to the purified diet prolonged growth and life somewhat, but animals receiving this ration, after developing a very serious disease of the eyes, also died without having reached adult life. But if part of the lard was replaced by butterfat in the diet of purified foods with whey added, the animals grew well for prolonged periods and did not develop the eye disease. It was apparent from these experiments that butterfat contains substances necessary for life, for growth of young animals, and for prevention of an eye disease. These substances supplied by butterfat are vitamin A and carotene, the latter of which can be converted into vitamin A in the body.

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WHAT IS VITAMIN A?

At least five different substances present in natural foods can supply vitamin A. Four of these are yellow pigments, soluble in fats but scarcely soluble at all in water, and very similar to one another. They are sometimes called the precursors of vitamin A. The fifth substance is vitamin A itself.

The chemical names for these four yellow pigments that the body can convert into vitamin A are α-carotene, β-carotene, γ-carotene, and cryptoxanthin. Under a microscope, these so-called carotinoids appear as beautiful orange-yellow needle-shaped crystals that form characteristic rosettes.

The chemical name "carotene" is derived from the word carrot. Yellow and leafy green vegetables are rich sources of the carotenes. β-carotene occurs in greater abundance and has wider distribution in actual foods than any of the others. The carotenes accompany the green coloring (chlorophyll) of all plants. Light seems to be of great importance in the production of the carotenes, as it is for the production of chlorophyll. In fact, the green or yellow coloring is a rough indication of the richness of foods of plant origin in carotene—the more intense the coloring, the greater the carotene content. Cryptoxanthin is one of the pigments of yellow corn, egg yolk, and green grasses.

In contrast to the carotenes and cryptoxanthin, vitamin A itself is not highly colored. This vitamin has been obtained in pure form from several different kinds of fish-liver oils. At ordinary temperatures vitamin A is a thick, pale-yellow liquid. By the use of very low temperatures Holmes and Corbet (*531*)[2] were able to obtain crystals of pure vitamin A. These appear as beautiful clusters of pale-yellow needles. For a given weight the crystals are over 1,000 times more potent in vitamin A value than the average medicinal grade of cod-liver oil.

Most natural fatty food products of animal origin contain some vitamin A. Animals convert the carotenes and cryptoxanthin of green leaves, grasses, and other feed into vitamin A in their bodies. Some of the vitamin appears in their body tissues, particularly in the liver, the kidneys, and to a lesser extent in body fat. In milk and in butterfat part of the vitamin A value is due to carotenes and part is vitamin A itself, converted within the cow from the carotene in her feed. Egg yolks contain cryptoxanthin and vitamin A, but usually very little of the three vitamin A-active carotenes. Cryptoxanthin is especially prominent when the hen's diet contains an abundance of yellow corn and grasses. Fish-liver oils are exceptionally rich in vitamin A, but relatively poor in carotene.

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[2] Italic numbers in parentheses refer to Literature Cited, p. 1075.

More detailed information on the chemistry of vitamin A, the carotenes, and cryptoxanthin is presented in a recent article by Palmer (*890*).

THE FUNCTIONS OF VITAMIN A IN THE BODY

Human beings, as well as animals, have a remarkable capacity for storing vitamin A in their livers. It is generally supposed that more than 90 percent of the total vitamin A content of the human body is present in the liver.

At birth infants have only very small stores of vitamin A. Human colostrum, which nature provides as the first food of infants, is several times richer in this vitamin than the mother's milk secreted at later stages of lactation. Because of the low vitamin A reserves of infants and because of their special need for vitamin D, physicians generally recommend giving infants small doses of cod-liver oil at a very early age. This would seem particularly important for the artificially fed infant.

The stores in the liver are called upon when the food intake does not provide adequate amounts of vitamin A. When these body stores have been practically exhausted, signs of vitamin A deficiency soon become apparent. Animals fed on rations very low in vitamin A value show evidence of several successive stages of deficiency, increasing in severity until death ensues. Practically all of these stages of vitamin A deficiency have at one time or another been observed in human beings also.

The earliest recognizable sign of such deficiency is night blindness, a visual abnormality that makes the eyes less responsive to dim illumination. After being exposed to a bright light, the eyes of a night-blind person cannot adjust in the darkness to the same low degree of illumination as can the eyes of well-nourished persons. Common examples of the difficulty a night-blind person has in seeing in dim light include his problem of visual adjustment when he enters a dimly lighted theater from a brightly illuminated entrance, or when driving an automobile he tries to see the dark road after a car with bright headlights has passed.

There are instances of night blindness which are not the result of vitamin A deficiency. Certain diseases of the eye are accompanied by poor vision in dim light, and a few persons are born with a permanent hereditary type of night blindness that cannot be relieved by increasing the intake of vitamin A or carotene. Night blindness due to vitamin A deficiency can be quickly relieved by increasing the intake of foods rich in vitamin A and carotene or by the administration of vitamin A or carotene concentrates.

A more severe or a more prolonged vitamin A deficiency results in extreme muscular weakness and changes in the structure of certain body cells—the epithelial cells—which form the protective covering of every surface of the body, including the surfaces of ducts and cavities within the body. The changes in these cell structures interfere with their proper functioning.

Late stages of such deficiency are accompanied by a serious type of eye disease known as xerophthalmia, which if it progresses leads to permanent blindness. This disease is rare in this country, but it has occasionally occurred. Many cases of xerophthalmia were observed during the World War among children in Denmark as a result of extensive exportation of dairy products with substitution at home of cheaper foods low in vitamin A value.

Vitamin A has sometimes been called the anti-infective vitamin, and its concentrates have been recommended for the prevention or cure of colds and other infections. According to the opinions of several medical authorities (*19*, *97*, *214*) who have published reports on this subject recently, there is no justification for believing that vitamin A has specific infection-preventive power. Whether or not an infection becomes established in the body depends upon a combination of circumstances. In many infections a deficiency of vitamin A is not involved at all. When the body contains a goodly store of vitamin A and the food is adequate in vitamin A value, no further resistance to infection can be secured by the administration of increased amounts of vitamin A-active foods or concentrates. However, when the body is suffering from a moderate or severe degree of vitamin A deficiency, most authorities are agreed that there would be a lowered resistance to infections. It is important to provide for fairly liberal stores of this vitamin in the body in order to bridge over periods of illness or emergencies attended with restricted vitamin A intake. This safeguard is also important because the absorption of vitamin A and carotene from the food may be low during illness.

A deficiency of vitamin A during the period of tooth formation results in defective tooth structures and striking deformities of the teeth (*780*). Wolbach (*97*) states that vitamin A deficiency during this period probably is the most important of all vitamin deficiencies in the human being.

THE DISTRIBUTION OF VITAMIN A VALUE IN FOODS

Vitamin A as such occurs only in food of animal origin. The vitamin A value of plant foods is due to the presence of carotenes and cryptoxanthin. The richest natural sources are the livers of various species of animals and particularly those of certain kinds of fish. The oils obtained from the livers of bass, eels, halibut, cod, and the tuna are extremely rich in vitamin A. The body oils of fish are much less rich than the corresponding liver oils. Muscle meats contain only traces.

Some foods of animal origin contain both vitamin A and the vitamin A-active carotinoids (carotenes and cryptoxanthin). Such foods include milk, butter, cheese, and egg yolks. A part of the carotene in the feed of the cow is converted into vitamin A and a part is secreted as carotene in the production of milk. The vitamin A values of milk and milk products are quite variable, depending on the amount of vitamin A or carotene in the cow's rations. During the summer months when the cows eat liberal amounts of fresh green grasses, the vitamin A value of the milk is relatively high compared to that of winter milk. Hens' eggs are richer in vitamin A value when the hens are fed rations high in carotene or vitamin A. Hens fed rations containing yellow corn usually transfer some of the cryptoxanthin of the corn to the egg yolks.

Most of the common fruits contain some carotene. Apricots, papayas, mangos, persimmons, and yellow peaches are among those which are important sources of carotene. Bananas, avocados, cantaloups, and oranges which have deep-yellow juice are good sources of carotene.

Leafy green and yellow vegetables are excellent sources of the vitamin A-active carotinoids. Kale, spinach, escarole, dandelion greens, watercress, turnip greens, lambsquarters, and parsley are some of the commoner leafy green vegetables that are very rich in carotene. In leafy head vegetables such as cabbage and lettuce, the outer green leaves are richer in carotene than the inner bleached leaves. Red and yellow carrots, yellow-fleshed sweetpotatoes, and ripe tomatoes are excellent sources of carotene.

The cereals in general are not important sources of vitamin A, and most of their vitamin A value is found in the germ and bran portions. Yellow corn is a richer source than the other common cereals used in this country.

QUANTITATIVE MEASUREMENTS OF THE VITAMIN A VALUES OF FOODS

The relative amounts of vitamin A and vitamin A-active carotinoids in foods can be measured by controlled feeding experiments with rats. Diets free of vitamin A but adequate in all other respects are fed to normal young rats until their body stores of the vitamin have been depleted. The body weights of rats that have reached this stage cease to increase and signs of an abnormal eye condition are apparent. The lids of one or both eyes become reddened and swollen, and an appearance of squinting suggests that the eyes have become unduly sensitive to light.

The food being tested for its vitamin A content is then fed as weighed daily supplements in such quantities as will promote a rate of growth equal to that induced by a standard quantity of pure β-carotene.

The International Unit of vitamin A is 0.0006 milligram of pure β-carotene. The quantity of a test food that must be fed daily to each rat in order to promote the same average rate of growth as is induced by feeding 0.0006 milligram of β-carotene per rat per day is said to contain 1 International Unit of vitamin A.

Foods tested in this way may contain both vitamin A and vitamin A-active carotinoids. The animal feeding tests do not distinguish between the growth responses due to vitamin A and these carotinoids, and for this reason the results of these measurements are usually expressed as total vitamin A value.

Animal feeding experiments are expensive, time-consuming, and laborious. Efforts are being made to develop chemical and physical methods of testing the vitamin A content of foods in order to overcome some of the disadvantages of the feeding experiments. Some progress has been made in this direction, but the application of these newer methods to measurements of the vitamin A values of natural foods often involves difficulties that have not yet been satisfactorily overcome. The chemical and physical methods are fairly satisfactory for measuring the vitamin A values of such materials as fish-liver oils and other vitamin A (or carotene) concentrates.

The chief interest in vitamins arises from the fact that they are of extreme importance in the nutrition of man and of animals. For this reason the acceptability of any and all chemical or physical measurements of vitamin A values must rest in the end upon their confirmation by animal or human feeding experiments.

VITAMIN A REQUIREMENTS

In order to determine the vitamin A requirements of man it is necessary to have a basis for distinguishing between nutritional states of adequacy and inadequacy of vitamin A. When such a basis is established it then becomes possible to restrict the vitamin A intake to the level which will just prevent the first signs of inadequacy. This quantity, expressed in terms of daily requirement, would represent a physiological minimum requirement.

Of the several recognizable signs of vitamin A deficiency, it now seems that nutritional night blindness is the earliest to appear. Several instruments are available for determining the presence or absence of night blindness in human beings. A measurement of the minimum intensity of light that the dark-adapted eye can see will indicate whether or not a person is suffering from night blindness. If foods or concentrates rich in vitamin A improve the visual adaptation to dim light, it may be assumed that a state of vitamin A deficiency existed for that person.

Friderischen and Edmund (*395*) have developed a method for measuring the visual adaptation of very young children (under 2 years of age) to dim light. The child is allowed to rest or sleep for some time in an unlighted room. Then graded dim lights are placed in front of the child while the observer watches him very closely. When the light is just bright enough for the child to notice, it will be indicated by movements of the child's brow and eyelids. A child who is not receiving a sufficient amount of vitamin A in the food will respond only to a light brighter than that to which well-nourished children respond.

The same principle is involved in measuring the visual adaptation of older children and adults, except that they are first exposed to the standard bright light and can tell the observer the moment the dim light used in the test is just bright enough to be seen by them.

The daily requirement for vitamin A for persons of different ages and of different body weights is usually expressed in terms of International Units of vitamin A or of weighed amounts of carotene.

Edmund and Clemmesen (*308*) have measured the vitamin A requirements of a group of Danish prisoners. Half of the men were given the ordinary prison rations throughout the experiment. The average daily amount of vitamin A contained in this diet was 1,200 International Units; during the summer months the vitamin A in the diet would naturally be a little more than that, and during the winter months it would be somewhat less. These investigators found that in this group some of the men developed signs of night blindness during the winter. The other half of the group was given a pint of whole milk daily during the winter in addition to the regular prison fare, so that they received an average of 1,400 International Units of vitamin A per day. There were no cases of night blindness in this group during either winter or summer. Edmund and Clemmesen conclude that an average of 1,400 International Units is the least amount of vitamin A which will just prevent night blindness in adults. These figures represent average intakes of vitamin A for a group of persons.

BUREAU OF HOME ECONOMICS VITAMIN A-REQUIREMENTS PROJECT

During 1937–38 the Bureau of Home Economics determined the vitamin A requirement by careful study of five adults. Three women and two men consented to be subjects for the experiment. For 5 to 6 months they ate only food prepared for them in the laboratory kitchen. Literally every bite that these people ate was weighed. Thus, it was made certain that each one was receiving an ample and constant supply of calories, protein, fat, calcium, phosphorus, iron, and of all the known vitamins (thiamin, ascorbic acid, vitamin D, and riboflavin) with the exception of vitamin A. The amount of vitamin A was kept as low as possible.

The diet was neither unpleasing nor unduly monotonous. The following list of foods from which it was chosen will show that there was opportunity for a moderate amount of variety from day to day:

Meats: Bacon, chicken, fish (lean), ham, lamb, pork, veal. All visible fat removed except in the case of bacon.

Vegetables: Asparagus (bleached), beans (dried), beets, cabbage (bleached), cauliflower, celery (bleached hearts), corn (white), cucumbers, mushrooms, onions, parsnips, potatoes (white), turnips (white).

Fruits: Apples, cranberries, grapefruit, grape-juice, grapes (white), lemons, pears, strawberries.

Miscellaneous: Cocoa, coconut, vegetable oils, egg white, flour (white), gelatine, honey, macaroni, milk (fat content less than 0.02 percent), oleomargarine (made with vegetable oil and containing no added vitamin A), rice, saltines, sugar, tapioca.

Breakfast was the least variable of the meals, consisting of grapefruit, toast, bacon, oleomargarine (with no added vitamin A), honey, skim milk, and black coffee. A representative dinner would be chicken, potatoes and oleomargarine, cauliflower, a small portion of cranberry sauce, pears, and skim milk. Supper: Navy bean soup, saltines, a small serving of apple, celery, and nut salad with lemon-juice dressing, cocoa, and angel-food cake.

There was a very small amount of vitamin A in this food, varying from 88 International Units a day for the smallest subject to 103 for the largest. The subjects neither lost nor gained in weight and appeared to be perfectly healthy throughout the experiment.

Before the subjects began to eat the experimental diet, a number of measurements of the ability of their eyes to adapt to darkness were made. This was done with a very sensitive instrument known as the visual adaptometer (fig. 1). By means of this instrument, the eye of the subject is exposed to a brightly lighted screen for several minutes; the screen is then removed and the subject is in total darkness. A test of his ability to see is then made immediately by flashing a small dim light placed slightly to one side of the center of the eye. The intensity of this light is increased until the subject sees it. This test is repeated every few minutes for about half an hour. The intensities of light a person requires at different times during the period of dark adaptation will show whether or not he is night blind.

While the subjects were on the diet, measurements were made every few days, until finally their eyes were found not to be capable of adapting themselves normally to darkness. The length of time before these signs appeared was not the same for all persons. One showed a change after only 2 weeks, two after 4 weeks, one after 6 weeks, and in the most extreme case, a change in dark adaptation occurred only after 18 weeks. These variations may be explained by the fact that each person had a different amount of vitamin A stored in his liver, depending on his past dietary history, and that probably each one was daily drawing on this store at a different rate.

When the adaptation to darkness had changed so that it was requiring 10 times as much light for the subject to see as when he was eating a well-balanced diet, vitamin A was added by giving cod-liver oil, which was carefully weighed into gelatine capsules. The amount of vitamin A in this oil was found by tests on rats according to the method described earlier. Small amounts were given daily at first, and these were increased slowly until the dose of cod-liver oil was reached that would again make the adaptation to darkness normal. As might be expected, the dose required was different for each individual and ranged from 1,200 International Units a day for the smallest to 3,800 for the largest. This was in addition to the very small amount already present in the diet. Even when the size of the person was taken into consideration, there was still a difference in the amount of vitamin A necessary for the different individuals.

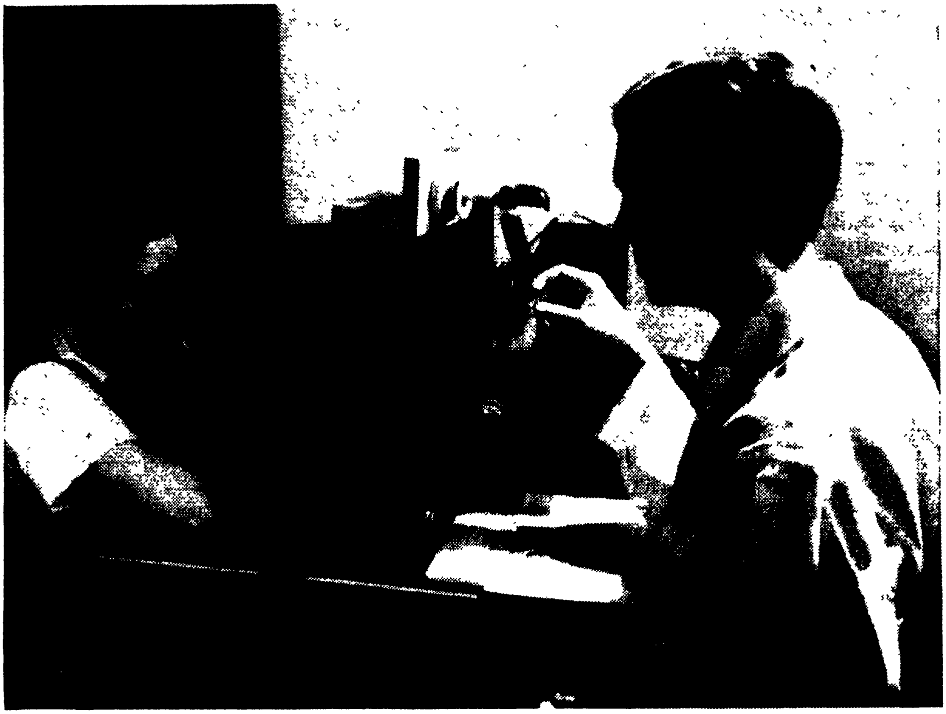

Figure 1.—Testing a subject for night blindness—the first symptom of vitamin A deficiency—with the visual adaptometer.

As soon as the adaptation to darkness had returned to normal, the cod-liver oil was withdrawn and the subject allowed to become night blind once more. This time, instead of cod-liver oil as the source of vitamin A, crystals of carotene dissolved in cottonseed oil were weighed into the capsules and given to the experimental subjects. Surprisingly enough, it was necessary to give each subject many more units in the form of carotene than they had required in the form of cod-liver oil in order to restore normal vision. This probably means that human beings are not able to use carotene as efficiently as they do vitamin A. It is not understood exactly why this should be true. Since vitamin A and carotene will not go into solution in water, but only in fat, it may be that the amount of fat in the diet has something to do with this lack of utilization of carotene. Work is now in progress at the Bureau to discover why the carotene is not better utilized.

Low-cost dietaries are dependent upon leafy green and yellow vegetables as the main source of vitamin A value. In such cases it would be very important that liberal amounts of these be included in order that there be no shortage of vitamin A in the body.

From the results of these experiments and the available data on vitamin A value or carotene content of different foods, it is possible to express the requirement in terms of quantities of common food items.

For children between the ages of 2 and 14 years a liberal amount of vitamin A will be provided if their daily food contains about 1 quart of whole milk in addition to an egg (or egg yolk), servings of green leafy vegetables and of butter suited to the size of the child, and a half teaspoonful of cod-liver oil or its equivalent in other fish-liver oils.

The vitamin A requirements of a normal adult can be supplied by a daily allowance of a pint of whole milk, one egg, two ordinary-sized pats (one-third of an ounce) of butter, and an average serving of a leafy green or yellow vegetable. It is not necessary to include exactly these articles of food, since many other foods rated as excellent sources of vitamin A will contribute comparable amounts of this vitamin. However, the group of articles specifically mentioned above offers a combination which supplies other nutritional essentials in very desirable allowances.

A pregnant or nursing woman requires more vitamin A than the ordinary adult. Her vitamin A requirements can be provided by including a quart of whole milk, an egg, an average serving of a leafy green vegetable, and one teaspoonful of cod-liver oil or its equivalent in other fish-liver oils in her diet each day.

VITAMIN B_1

by O. L. Kline[3]

WHAT used to be known as vitamin B was later found to be a complex of several vitamins. One of these is now called vitamin B_1; another is vitamin G, or riboflavin. The old vitamin B is now generally referred to as the vitamin B complex.

Vitamin B_1 is an essential dietary substance that cannot be synthesized in the normal processes of the human body and must therefore be supplied in the diet. This vitamin appears to play a role in the metabolism of every living cell in the lower animals and plants, as well as in the human body. It is required for normal growth of all species of animals, of yeasts and molds, and of higher plants. Plants have the ability to manufacture and store it in the seed, principally in the germ, and yeasts grown on media having considerable quantities of the vitamin or its constituent parts contain comparatively large amounts of it. On the whole, however, dietary vitamin B_1 is derived from a large variety of foods that contain only small amounts of the vitamin. Therefore a subnormal supply of vitamin B_1 in our dietary is likely to occur only under unusual circumstances.

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VITAMIN B_1 DEFICIENCY DISEASES

A lack of vitamin B_1 in the diet causes the human deficiency disease, beriberi. This disease has had widespread occurrence, particularly in the Orient, including the Philippines, among people whose principal article of diet is polished rice, refined by a milling process that removes the vitamin-containing outer coat of the seed. The disease, which has been known for a long time, was first shown to be due to an unbalanced diet in 1883, when an outbreak of beriberi in the Japanese Navy was controlled and further outbreaks prevented by supplementing the usual diet of polished rice and dried fish with meat, vegetables, and milk. The isolation and identification of vitamin B_1 as the substance necessary to prevent beriberi were the result of a long series of investigations begun by Eijkman (*313*) in 1897 and carried on by research workers in many parts of the world. The story of the development of the vitamin theory and identification of many of the dietary factors is a long and interesting one that extends over a period of more than 40 years. During that time a science of nutrition has grown up that gives us an insight into the structure and function of many of these vital substances.

Although a complete lack of vitamin B_1 in the human dietary may result in the occurrence of beriberi, there may be many degrees of the deficiency causing less well-defined symptoms. Any degree, from the mild form in which slight and unrecognizable symptoms occur, to the extreme case with severe metabolic disturbances, may occur in persons of all ages. Infantile beriberi has a rapid onset with short duration, leading to death if untreated, while adult beriberi in most cases develops gradually with vague and ill-defined symptoms. In the early stages the adult may complain of fatigue, stiffness, headache, nervousness, and loss of appetite. Later any one of these three types may be recognized: (1) The so-called wet beriberi type (called wet because of the appearance of large amounts of fluid in the tissues, causing a generalized edema), regarded by some investigators as a critical stage in the development of the disease, in which swelling of tissues is probably caused by improper functioning of the heart; (2) dry beriberi (so designated when the predominating symptom is a peripheral neuritis), considered to be a chronic form which may persist over a long period with possible involvement of nervous system changes; and (3) a type described by some observers as acute pernicious beriberi, in which enlargement of the heart and related conditions may be found. The occurrence of peripheral neuritis, involving the nerves at the periphery or ends of the nervous system—also called polyneuritis—is a common symptom in the advanced stages of all these types of beriberi. Polyneuritis is a condition in which control of the muscles is affected, causing a loss of coordination in the movements, particularly, of the feet, legs, and arms. In severe cases even the muscles of the trunk may be affected. Patients in such advanced stages of the disease develop ataxia—uncontrolled muscle contractions—and lack of coordination.

This deficiency disease is of course prevented by the use of well-balanced diets. Cure may be effected by administration of concentrates of vitamin B_1 or the crystalline vitamin itself, or if these are not available, such diet supplements as yeast, wheat germ, or rice polishings. A well-balanced diet is a further essential part of the curative procedure. It seems clear that although the primary deficiency in beriberi is vitamin B_1, there may be a lack of other nutritional factors as well, factors that can most successfully be supplied by proper dietary means. This is true in the case of other dietary deficiencies also, but particularly true of vitamin B_1 because an early symptom of the disease, loss of appetite, results in reduced food intake, and in turn a reduced supply of other essential substances. For this reason the symptoms of beriberi are more variable and less well defined than those of some other deficiency diseases such as scurvy or rickets.

Less commonly occurring conditions reported to be relieved by vitamin B_1 therapy are the polyneuritis of pregnancy, the polyneuritis which sometimes occurs in late stages of acute alcoholism, and the polyneuritis associated with human pellagra. In these conditions a decreased assimilation of food may lead to a reduced intake of the vitamin, so reduced in a few extreme cases as to cause the polyneuritic symptoms to appear. That vitamin B_1 is the sole factor involved in these instances can only be demonstrated in further clinical studies in which the crystalline vitamin is employed.

CHEMICAL NATURE OF VITAMIN B_1

It was not until 1936, nearly 40 years after vitamin B_1 deficiency was first produced experimentally by Eijkman, that chemists were successful in synthesizing the compound in the laboratory. The American chemist, R. R. Williams, was the first to describe the synthesis of the vitamin (*1228*, *1229*) and as a result of these and other studies, crystalline B_1 is now available in pure form at low cost. It is being widely used in the study of the physiological function of the vitamin in the human body, and in clinical studies designed to measure the human requirement more accurately.

The crystalline vitamin has been named "thiamin chloride" (in Europe it is called aneurin), although the term "vitamin B_1" is still widely used both in the scientific literature and in popular discussions. This vitamin, like other members of the vitamin B complex, is soluble in water but insoluble in most fat solvents. It is destroyed by heat in the presence of moisture, the rate of destruction depending on the acidity or alkalinity of the medium. In alkaline solution destruction by heat is rapid and complete in a short time; in acid reaction the vitamin is somewhat more stable. A common method for destroying vitamin B_1 in experimental studies is autoclaving, in which the material treated is subjected to an atmosphere of steam under pressure. However, in ordinary cooking of foods, vitamin destruction is not so marked, and it apparently varies with the kind and the acid reaction of the food. Because of the water solubility of the vitamin, a greater loss may occur when cooking waters and juices are discarded.

Other causes of B_1 destruction of less practical importance but worthy of mention here are its possible reactions with other compounds sometimes present in foods. The vitamin is known to unite with compounds that render it physiologically inactive, such as aldehydes. It is well known also that the vitamin is destroyed in the presence of sulfites. Such factors may be of real importance when compounds of this type are used in food processing or preservation. However, with reasonable care in preparation of foods, either in cooking, processing, or preservation, important amounts of vitamin B_1 need not be lost.

VITAMIN B_1 REQUIREMENTS

The human body is unable to store large amounts of vitamin B_1; therefore it is important to maintain a constant supply in the diet. This requirement, however, is adequately met in most diets in this country made up of the ordinary foods, although such processes as the milling of grains to produce a refined grade of flour, the polishing of rice to improve appearance and keeping quality, and the sulfuring of fruits do tend to reduce the B_1 content of our diets.

Vitamin B_1 is essential for the well-being of every living cell. This is necessarily true since this vitamin is concerned with the metabolism or break-down of foods that furnish energy for the body processes and functions. Biological research in recent years has revealed the complex steps through which the carbohydrate foods are broken down during the process of digestion and metabolism in order to release in an available form the energy from the sun originally bound up in those compounds by the plant. The vitamin acts in combination with phosphoric acid as a coenzyme called cocarboxylase, which functions to prevent the accumulation of pyruvic acid, an intermediate compound formed in the break-down of carbohydrates. Thus, the amount of vitamin B_1 required each day by a man or an animal depends directly upon the amount of energy that man or animal expends.

In estimating the requirement for the vitamin, certain variables must be considered. For example, it has been demonstrated that there is a smaller demand for the vitamin when diets containing a large proportion of fat are consumed. This is to be expected, since the energy derived from fat is made available by a chain of chemical reactions in which vitamin B_1 is not directly necessary. Therefore, the vitamin requirement bears a direct relation to the number of nonfat calories (carbohydrate and protein) used by the body.

In general, three different methods of approach have been used in studying the human requirement for vitamin B_1. These are studies of (1) the quantitative relationship of the vitamin to body weight, body activity, and food calories utilized in different species of animals; (2) the B_1 content of various diets, including those known to be adequate and those known to allow the occurrence of beriberi; and (3) the clinical administration of concentrates of the vitamin on a large scale. The values to be discussed have been obtained by these methods and must be considered as the minimum requirement. There is little agreement as to the increased amount that may be required for optimum conditions. It is hoped that improvements in methods for determining the vitamin B_1 content of blood and urine and the use of crystalline B_1 in clinical studies will yield in the future more reliable information on the minimum, as well as optimum, requirement.

Vitamin B_1 values are most often expressed in International Units, 1 of which is equivalent to 3 micrograms, or three-millionths of a gram, of the pure crystalline B_1. Another unit widely used in the past was the Chase-Sherman. The relationship now generally accepted between these two is that 1 International Unit is equivalent to 2 Chase-Sherman units. The International Unit is based on a definite weight of the pure vitamin; the Chase-Sherman unit is based on growth response in the rat under standard conditions.

The formula proposed by Cowgill (*235*) for estimating the minimum daily vitamin B_1 requirement for normal adults indicates that this value depends both upon body weight and upon the number of food calories utilized. By means of this formula one may calculate that a man of an average degree of activity, weighing approximately 140 pounds, will require a minimum of 250 International Units of vitamin B_1 a day, while a woman of 100 pounds will need at least 135 International Units. Another American writer, Rose (*983*), has recommended, as a more liberal allowance for the adult, amounts approximately equivalent to 350 to 450 International Units daily. It seems clear from this and other evidence that by the best means of calculation based on body weight and activity, minimum daily need falls between 135 and 450 International Units (or 0.4 to 1.35 milligrams) of the pure vitamin.

From a study of the vitamin B_1 content of many human dietaries, the adequacy of which with respect to prevention of beriberi was known, it was estimated that the normal daily B_1 intake of the adult is 350 International Units and that a minimum of 150 units is needed to prevent occurrence of gross symptoms of beriberi. A group of German investigators (*1102*) have reached a similar conclusion, reporting a minimum requirement of 85 to 150 International Units and stating that intakes of 350 to 700 will meet the needs under any conditions. VanVeen (*1165*), who studied beriberi in the Orient, has determined by feeding concentrates of B_1 that the minimum daily intake for prevention of this disease when diets containing large amounts of starch are consumed is 100 to 200 International Units daily.

Values obtained from studying the excretion of vitamin B_1 by persons consuming both adequate and vitamin B_1-deficient diets are found to fall in the same range. Harris and Leong (*482*) have estimated that approximately 8 percent of the intake of this vitamin is normally excreted, and on this basis excretion studies indicate that the normal adult requires at least 200 International Units daily.

It should be noted that all of these values have been obtained by indirect means, without knowledge of the exact function of the vitamin in the body. The fact that the values fall within a small range is an indication of their accuracy. More exact knowledge of adult requirements must await a better understanding of vitamin function and more accurate clinical studies. These values ranging from 85 to 700 International Units correspond to 0.25 to 2.1 milligrams of the pure vitamin B_1.

The infant's requirement for the vitamin has been difficult to determine. Based upon the vitamin B_1 content of milk, it has been estimated that infants under 6 months old probably obtain not more than 50 International Units of the vitamin a day.

The requirement of children has been even more difficult to measure than that of infants or adults. Since the vitamin is essential for growth, a limited or deficient intake would be expected to limit the rate of growth of the child. Beriberi does not commonly occur in children, probably because the growing organism adjusts itself to the lowered vitamin intake by a reduction in rate of growth, thus conserving the small amount of vitamin B_1 available. In the majority of clinical studies on children vitamin B_1 supplements other than the crystalline vitamin have been employed, and therefore conclusions from these studies are subject to some criticism. It is reasonable to expect that, as in the adult, the requirement of children may depend upon the amount of carbohydrate food utilized. This would place the requirement of growing children in the same range as that of adults.

The amount of vitamin B_1 needed by the female is increased during pregnancy and lactation. Studies indicate that this is true of a number of other nutritional factors, and such increased demand is not unreasonable. It has been noted, particularly in the Far East (*1229*), that an apparently normal woman may develop beriberi soon after the birth of her first child, and although in a partly paralyzed state will secrete sufficient quantities of milk for support of the infant. However, since the amount of vitamin B_1 secreted in the milk is dependent upon the mother's diet, such infants invariably develop infantile beriberi and soon die unless treated. The increased amount of vitamin B_1 needed in pregnancy may be considered as the requirement for the mother plus the amount needed by the fetus. After birth of the infant, the normal secretion of milk creates an increased demand for the vitamin. Cowgill (*236*) has recommended for pregnant and lactating women an intake of 20 International Units per 100 calories of food, or 600 to 700 International Units a day.

Data obtained in the Bureau of Home Economics in a study of a large number of dietary records from families at various levels of food expenditure indicate that those diets that provide at least the minimum daily requirements for calories, protein, calcium, phosphorus, and iron usually furnish 200 or more International Units of vitamin B_1 a day. Stiebeling and Phipard (*1104*) state that about 10 percent of the white families studied selected foods that furnished less than 300 International Units a day, while the diets of about half the families investigated furnished 500 or more.

The vitamin B_1 requirement is known to be increased in certain clinical conditions. Since, as has been pointed out, the requirement depends on energy expended, and therefore on rate of metabolism, any increase in metabolic rate such as occurs in cases of high fever or of heightened metabolism due to an overactive thyroid gland, may result in an increased demand for vitamin B_1. If the amount of food energy utilized is double the normal, then presumably the need for the vitamin will be doubled. Cowgill (*236*) has suggested that a good practical rule to follow in such cases is to be assured of an intake of about 20 International Units of vitamin B_1 per 100 calories. This would seem to allow for a considerable factor of safety.

Other clinical conditions that may affect the vitamin B_1 requirement are those in which large amounts of water are excreted, such as diuresis and diarrhea. This vitamin is water-soluble, and such conditions would tend to cause a washing-out effect. In diseases which involve a large loss of water it is well to pay attention to the vitamin supply.

VITAMIN C

by Sybil L. Smith[4]

TO THE neglect of an attendant and the keen observation of a brilliant scientist we owe what is probably the first description of experimentally induced scurvy and lowered resistance to infection due to a diet lacking in vitamin C.

About 45 years ago Theobald Smith, then Chief of the Pathological Division of the Bureau of Animal Industry, was using some guinea pigs to test the virulence of certain organisms that had been isolated in the study of a disease of swine. He was getting irregular results; two of his guinea pigs, No. 254 and No. 255, were killed by an inoculation that they should have been able to resist easily. He began casting about for the cause of this susceptibility. He found it in the diet the animals were receiving. He wrote in his annual report for 1894–95 (*1084, p. 172*):

> The death of No. 254 was undoubtedly due to the absence of such [green] food as the attendant had neglected to provide it after the disappearance of grass in the fall of the year. Furthermore, No. 255 was weakened by the restricted diet and succumbed to an inoculation which otherwise might have had no visible effect.

Not only were these animals unusually susceptible to infection; they developed, Dr. Smith noted, a "peculiar disease" of their own, which he described as follows:

> When guinea pigs are fed with cereals (bran and oats mixed) without any grass, clover or succulent vegetables such as cabbage a peculiar disease, chiefly recognizable by subcutaneous extravasation of blood [that is, hemorrhages under the skin], carries them off in four to eight weeks.

But Smith's work was with domestic animals and not human beings, and since poultry, swine, and cattle manufacture their own vitamin C and do not need to have it furnished in their food as do guinea pigs, monkeys, and human beings, he naturally did not associate this disease of improperly fed guinea pigs with the recognized but little-understood symptoms of human scurvy. It was not until more than 10 years later that this connection was made by some Norwegian investigators (*533, 534*) who found that a disease very prevalent among sailors on long voyages was identical in its symptoms with guinea-pig scurvy, and like guinea-pig scurvy could be cured by green food such as cabbage, or, more spectacularly, by orange juice or lemon juice.

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After the recognition of human scurvy as a vitamin-deficiency disease, 25 more years elapsed before the substance responsible for its prevention and cure—which was given the name vitamin C as the third vitamin to be recognized—was finally separated from foods, identified as a chemical compound of known structure, and manufactured for use in laboratory and clinical work (*629*). But even now, more than 6 years later, there is still considerable uncertainty as to how the vitamin acts in the body and how much of it is needed by people of different ages.

One difficulty is that it is no longer a question simply of determining the quantity of the vitamin necessary to prevent the symptoms of scurvy—soreness and stiffness of the joints, swelling and bleeding of the gums with loosening of the teeth, and hemorrhages under the skin on various parts of the body. These more severe symptoms are now so seldom seen in this country that when cases of undeniable scurvy are found they are given considerable attention in medical journals and are even considered news by the popular press. This does not mean, however, that there is no occasion for most of us to worry about lack of vitamin C. On the contrary, there are probably thousands of people in this country who are suffering from an unrecognized deficiency of vitamin C. Many vague symptoms of ill-health, such as restlessness and irritability in infants and children and a run-down feeling in adults, particularly in the early spring (spring fever), are probably due to lack of vitamin C. In fact, even when there is not a single outward symptom of trouble a person may be in a state of vitamin C depletion more dangerous than scurvy itself. When such a condition is not detected and continues uncorrected, the teeth and bones may be damaged and, what may be even more serious, the blood system may be weakened to the point where it can no longer resist or fight infections not so easily cured as scurvy.

Another difficulty that has stood in the way of determining vitamin C requirements with the exactness that should be possible for a definite food constituent is the peculiar nature of the vitamin. Consequently, it may be well to review briefly what is known about the chemical nature of the vitamin and its reactions in the body.

WHAT IS VITAMIN C?

Pure vitamin C can be purchased in the drug store as small white tablets labeled "Cevitamic Acid." A name more commonly used as a substitute for vitamin C is "ascorbic acid." Both of these names indicate that the vitamin is an acid; and it does have a slightly sour taste suggestive of acids.[5] Chemists speak of vitamin C as an oxidizing-reducing agent. This means that under certain circumstances the

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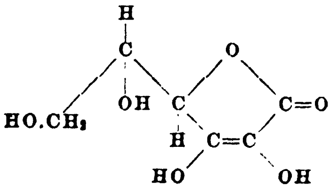
[5] The simplest chemical formula is $C_6H_8O_6$; but the structural formula, which shows how these carbon, hydrogen, and oxygen atoms are joined together, is not so simple, as shown below:



vitamin can unite with oxygen (oxidation) and under others with hydrogen (reduction). In living tissues, both animal and plant, the vitamin is ordinarily in the reduced form, as pictured in the footnote. In the animal body there seems to be a substance—an enzyme—that tends to keep the vitamin in the reduced form, but in blood that has been drawn for test purposes and in urine there is no longer such protection and the vitamin is very easily converted to an oxidized form in which it is no longer active and from which it cannot be changed back. In plant materials the vitamin is also fairly easily oxidized, and when this happens, as in foods that are exposed too long to the air, it cannot be changed back to the active reduced form. Such foods are consequently no longer effective sources of the vitamin. Moreover in the body itself some of the vitamin C taken in foods or even as pure ascorbic acid may be destroyed before it can be used. All of this means that vitamin C is quite unstable and easily lost.

Figure 2.—**Measuring the vitamin C in oranges.**

The chemical methods used to determine how much vitamin C is present in any material are usually color tests depending upon the reducing property of the vitamin, which changes the color of the testing substance; but thus far no test has been found that will react with vitamin C and not with other reducing agents. As vitamin C reacts more rapidly than the other reducing agents likely to be present, considerable reliance is placed on completing the test within a very short time—30 seconds at the most. Much time has been spent in many laboratories in attempting to find a completely satisfactory method of measuring vitamin C (fig. 2). This to some extent explains why it is taking so long to find out all that should be known about the part this important vitamin plays in human nutrition.

HOW DOES VITAMIN C ACT?

Some idea of how vitamin C acts in the body to prevent all of the visible and invisible ills that have been described and to strengthen the body's resistance to infection has been obtained from careful study of guinea pigs. It is possible by certain chemical tests to trace the vitamin as it is used by the body, and on observation to note the changes taking place when the vitamin is added or taken away. Such studies (*1248*) have shown that in guinea pigs an important change takes place around the cells in certain tissues, such as the marrow of the bones, the dentin that composes the principal mass of the teeth, and various connective tissues throughout the body. Normally these cells are surrounded by a stiff jellylike or cementlike substance, which in animals deprived of vitamin C becomes a thin watery liquid powerless to support the cells. When the vitamin is again supplied, the substance resumes its jellylike state. The thickening is similar to the effect of pectin in making jelly.

Undoubtedly many of the results of vitamin C deficiency are due to this liquefying of the intercellular substance. There is little question that this is so in and around the teeth, the bones, and the joints. Whether the break-down in the blood capillaries resulting in hemorrhages is due to a similar change or to some failure in the oxidation-reduction system is not definitely known. In a recent review (*250*) in which the effects of vitamin C deficiency are discussed, much emphasis is given to the effect of growth and stress in determining where the most evident harm results from a lack of vitamin C. In growing children it will be in the developing bones and teeth. There may be some truth in the expression "growing pains." The stress of exercise or muscular work in older people determines where the breakdown of the capillaries will occur and hemorrhages appear.

Another effect of lack of vitamin C that may be traceable to the failure of the intercellular material to jell is delayed healing of wounds. It has been demonstrated in guinea pigs (*664*) that artificially produced wounds heal much more slowly when the animals are on diets low in vitamin C than when they are given plenty of the vitamin; and it has also been shown that during the slower healing process the wound tissue ruptures very easily. These results are thought to explain occasional breaking open of wounds with no evidence of infection in human beings. A study of the diet of such patients would probably show an inadequate supply of vitamin C. Peptic ulcers might be thought of as wounds, and it is now considered the best practice to prescribe additional vitamin C for ulcer patients. In the past, quite unwittingly, ulcer diets were actually almost entirely lacking in vitamin C, for the bland foods prescribed—milk and eggs—contain little or none of this vitamin.

It is a temptation to go on illustrating how vitamin C acts by showing what it does, but one more illustration will have to be enough at this point—the relation of vitamin C to infections.

After it became possible to determine the intake and output of vitamin C in the body it was found that a great deal more of it disappears during various infections than under normal conditions. Tuberculosis is an infectious disease in which there is a great drain on vitamin C, and for a long time it has been the custom to prescribe rather large amounts of orange juice or tomato juice in the dietary treatment of the disease.

At first it was thought that the vitamin was destroyed by the organisms producing the infection, but there is now some evidence that it actually plays a part in combating the infection because it is necessary for the proper functioning of the blood-serum complement--a substance in the blood stream that acts as the first line of defense against invasion by harmful agents. It has recently been shown in guinea pigs (*290*) that the blood-serum complement loses its normal activity in the absence of vitamin C. In human beings, too, blood analyses (*207*) have shown that a high content of vitamin C is accompanied by a high content of blood-serum complement, and vice versa. Just what reaction, if any, takes place between the blood-serum complement and vitamin C is not yet known. Both are oxidizing-reducing agents, and it is probably through this property that they act together in defending the blood.

JUDGING THE STATE OF VITAMIN C NUTRITION

As the first step in determining vitamin C requirements it is necessary to set up certain standards for comparison—a difficult task when mere prevention of scurvy is no longer the goal. At one end of the scale there should be a standard representing the amount of vitamin C that would prevent the first detectable sign of vitamin C deficiency. This would be the physiological minimum. At the other end there should be a standard representing the amount that would result in a state of health that could not be bettered by further additions of vitamin C. This would be the optimum. In the wide zone between these extremes it might be advisable to set up another standard that would represent adequacy but not liberality and provide for fair health as contrasted with buoyant health.

At present there are three yardsticks in use, singly or in combination, for arriving at these more or less arbitrary standards. These are the capillary-resistance or fragility test, which measures the strength of the blood capillaries; determination of the vitamin C content of the urine, which measures the amount of the vitamin excreted and, in connection with knowledge of the vitamin content of the food, shows how much has been used or lost in the body; and determination of the vitamin C content of the blood, which shows how much of the vitamin is ordinarily in circulation.

CAPILLARY-RESISTANCE TEST

One of the first standards to be used involved capillary resistance. It was assumed that the slightest evidence of a weakened capillary system, such as the production of tiny hemorrhages, called petechiae, under the skin on moderate pressure represented the border line between an abnormal and a normal condition of vitamin C nutrition. The test consists in applying pressure to the upper arm by means of an instrument similar to the familiar blood-pressure apparatus of physicians and counting the number of petechiae produced, or reversing the process and pumping air out by means of a tiny suction cup and counting the petechiae produced by the suction. The two methods are known as the positive (*417*) and negative (*249*) pressure methods, and standards for different degrees of vitamin C undernutrition are based on the number of petechiae produced at a given pressure.

It was first thought that the test would prove very practical for survey work with school children or any population group, but it has not met with much favor in this country. One reason is that the capillaries may be weakened from other causes than lack of vitamin C. An even stronger reason, for which there is cause for congratulation, is that the vitamin C nutrition of people in this country is seldom low enough for this test. In more northern countries in which the supply of vitamin C-rich foods runs very low in the winter, a large portion of the population is likely to react to the test before the winter is over. In Sweden, where the positive-pressure test was developed, it is said to be very useful as a means of detecting those most in need of vitamin C supplements (*419*).

EXCRETION TEST

As soon as the chemical nature of vitamin C became known and color tests were developed for measuring it in foods and body fluids, attempts were made to set up standards of normality by measurements of the amount excreted day by day by healthy people. These tests have not been altogether satisfactory for many reasons, but particularly because of the great activity and instability of the vitamin and the possibility that the test measures other reducing substances as well as vitamin C. However, certain standards, based on the results of many studies in different parts of the world, are in use until more accurate ones can be developed. As these standards are always expressed in milligrams of ascorbic acid it may be well at this point to state that 50 milligrams of ascorbic acid corresponds to the amount of vitamin C furnished by about a scant half cupful, or about 4 fluid ounces, of orange juice. A small fruit-juice glass holds about this same volume.

The procedure, which has been used very extensively, is to collect all the urine voided during a 24-hour period with elaborate precautions to prevent loss or destruction of the vitamin and measure the vitamin content of the separate or combined samples. Generally, the procedure is repeated for 2 or 3 days and the results are averaged. For an adult an average daily excretion of about 13 milligrams of ascorbic acid has been considered by some investigators (*3*, *481*) to indicate that the vitamin C intake has been barely enough to provide the minimum physiological requirement, while 20 milligrams indicates a fairly low but perhaps adequate intake, and 40 milligrams a liberal intake. These standards are being applied in some studies now going on in several State experiment stations in the Northeast and Northwest.

Unavoidable and unknown losses not connected with the use of the vitamin probably take place as it goes through the body, and it is also possible that the test may measure other substances similar in certain properties to vitamin C. It is now customary, therefore, when possible, to follow up this measurement of vitamin C on the subject's ordinary diet by similar tests made after he has taken a large dose of pure vitamin C—crystalline ascorbic acid. An increased output under these conditions cannot be attributed to anything but vitamin C. If the person undergoing the test has been taking as much vitamin C day by day in his diet as he can use, by far the larger part of the extra dose will appear in the urine within 12 or 24 hours. If there is no increase in the output following the test dose, it is almost certain that more vitamin C is needed, and the test dose is repeated for several days until there is a sudden and marked increase in the output of vitamin C. In the use of this method there has been so little agreement as to the size of the test dose, the method of giving it, the end point, and the final calculations of the data that no one standard can be given at this time. The one most frequently used as representing normal conditions is the excretion of 50 percent or more of a test dose of 300 to 500 milligrams within the first 24 hours, or of a dose half this size within 12 hours (*588*). The test in a considerably shortened form is being used in judging the vitamin C nutrition of groups of people, particularly children (*480*).

Analysis of the output of vitamin C may seem to be a roundabout method of estimating intake, but unless analyses for vitamin C are made of all foods eaten that may be expected to furnish appreciable amounts of this vitamin, the intake cannot be determined with any degree of accuracy because of the wide variations in vitamin C content of the same food item (except possibly citrus fruits) as affected by variety and method of treatment.

BLOOD TEST

The third yardstick for estimating the state of vitamin C nutrition is measurement of the vitamin C content of the blood in fasting condition, that is, sufficiently long after food has been taken that the immediate effects of the most recent supply of vitamin C are over. From many determinations on subjects of all ages it has been found that the content of vitamin C in the blood of normal persons under these conditions does not vary with age but that within certain limits it is dependent on the previous dietary intake of vitamin C (*6*, *8*, *439*, *925*). The range extends from a minimum of about 0.6 milligram to a maximum of 1.5 to 2 milligrams or more per 100 cubic centimeters of blood.

Generally speaking a person whose blood has a vitamin C value of 0.6 milligram is just about on the border line between inadequate and adequate vitamin C nutrition, and one whose blood has a value of at least 1.5 milligrams is likely to have excellent reserves of the vitamin. According to some investigators (*311*) a blood content of 0 to 0.4 milligram per 100 cubic centimeters shows a very poor state of vitamin C nutrition; 0.4 to 0.8 milligram a moderately good state; 0.8 to 1.2 milligrams a very good state; and above 1.2 milligrams an excellent state. From capillary-resistance tests and determinations of the vitamin C content of the blood in the same subjects (*419*) it has been concluded that the blood values corresponding to the point at which the capillaries first break down are as low as 0.14 milligram per 100 cubic centimeters, which is rather far down in the range of values just noted as showing a very poor state of vitamin C nutrition. This shows that the physiologically minimum requirement, as measured by capillary resistance, is considerably below the requirement for satisfactory nutrition.

METHODS OF DETERMINING VITAMIN C REQUIREMENTS

The logical procedure for determining vitamin C requirements of any age group is to select normal healthy subjects and deprive them of vitamin C until their capillary resistance, blood, or urine values have dropped below the standards just discussed and then add the vitamin gradually until the standard values are again reached. This is a tedious process beset with many difficulties, open to many errors, and subject to many interpretations, but as a matter of fact most of the attempts that have been made to determine human requirements have been based on some part of the general scheme here roughly outlined.

The first application of this principle, and indeed the first attempt to use human beings instead of guinea pigs in the study of vitamin C requirements, was made in Sweden only 8 years ago by Göthlin (*416*), the investigator who has found the capillary-resistance test so useful in detecting vitamin C undernutrition in children. Following the plan exactly as outlined, he kept two adults on a milk-and-egg diet until their capillaries broke down under the test. Then step by step he built up the strength of the capillaries by small additions of orange juice to the milk-and-egg diet, until a point was reached at which the small hemorrhages, or petechiae, no longer showed when the test was applied. The amount of orange juice being fed at that point was considered to furnish the minimum physiological requirement of vitamin C. Later when pure ascorbic acid became available Göthlin and his associates (*418*) repeated the test with similar results.

The second yardstick, the content of vitamin C in the urine, has been used in so many ways that only one or two can be mentioned here by way of illustration. It was at first thought, quite naturally, that the differences between the vitamin C content of the food eaten and of the urine excreted would represent the amount used by the body, that is, the requirement; or that by adjustments in the amount consumed an amount would be found on which the body would be in equilibrium, with intake and output just balancing each other. Both of these methods have been used, but in the first there is the puzzling question of what becomes of some of the vitamin, for there is no constant relation between increased intake and output. The second method measures minimum or barely adequate rather than optimal requirements, and again there are discrepancies difficult to explain.

Many investigators believe that optimal nutrition, the state of health which cannot be bettered, is best secured by giving all of the vitamin that the body can hold. This state is commonly called saturation and is measured by the spill-over of vitamin C into the urine that occurs after repeated large doses of the vitamin are given. The procedure being followed at the New York (Cornell) Agricultural Experiment Station (*92a*) in attempts to determine the saturation requirements of young people illustrates this use of urinary-output values.

The test consists in first saturating the subjects with vitamin C by daily intakes of 200 milligrams of ascorbic acid (equivalent in vitamin C to two cupfuls of orange juice) for 6 days, or until they are completely saturated as shown by a marked increase in output following a still larger dose of 400 milligrams. The entire test is repeated two or three times to get the average output of the saturated subject after a 400-milligram dose. Then a small daily dose is given for a week with a 400-milligram dose at the end—and the dose is gradually raised week by week until the output following the 400 milligrams is the same as in the preliminary saturation test. If repeated trials at this level give the same results the dose is considered to be the minimum allowance for saturation of the tissues.

A definite relationship has been found between the initial vitamin C content of the blood and the total quantity of the vitamin required for saturation as just described. For instance, it has been found (*311*) that in persons with a vitamin C content of the blood of only about 0.4 milligram per 100 cubic centimeters, saturation was not reached (as determined by a marked increase in output) until a total of 2,000 milligrams of ascorbic acid had been given, whereas in persons with an initial blood value of 0.8 milligram per 100 cubic centimeters, only 1,000 milligrams of ascorbic acid were required for saturation. Consequently, it is thought that the degree of vitamin C saturation of any subject can be estimated by a single blood determination in place of the tedious urinary-excretion tests. This would considerably shorten the method of determining saturation requirements.

DOES SATURATION REPRESENT OPTIMAL VITAMIN C NUTRITION?

This is a question on which there is a decided difference of opinion. Some investigators feel that it is an unnecessary extravagance to push up the vitamin C intake until the body is saturated and can take no more. Some suggest that it may be actually harmful to do so, although others point out that the body takes care of the excess by excreting what is not needed. As the beneficial effects of vitamin C in other ways than preventing scurvy are becoming more and more evident there is a growing tendency to push up allowances in order to provide for all emergencies.

One of the most convincing arguments for generosity to the point of saturation in recommended allowances has recently been brought forward by Szent-Györgyi, the Hungarian investigator who discovered the unusual acid later identified with vitamin C. Szent-Györgyi (*1118*) has pointed out that a caged guinea pig kept in a laboratory away from sources of infection may get along in an apparently healthy condition on as little as 1.5 to 2 milligrams of vitamin C daily. Much more of the vitamin is needed, however, to protect the animal against bacteria or disease toxins, and as much as 20 to 40 milligrams a day for complete saturation of the tissues, as determined by the test-dose method just described for human beings. Furthermore—and this point is considered of great significance—this larger amount of vitamin C, from 12 to 20 times as much as the minimum protective dose, is no more than the guinea pig gets daily when it is allowed to eat all the green food it wants. Probably the guinea pigs that the Bureau of Animal Industry was using in the classic experiments described at the beginning of this article were getting 20 to 40 milligrams of vitamin C daily before the grass was no longer to be had, and it was not until "the disappearance of the grass in the fall of the year" that some of the animals "succumbed to an inoculation which otherwise might have had no visible effect."

If the amount of vitamin C a guinea pig naturally consumes daily from its green food is the same as is needed to saturate its tissues, is not saturation the optimal state? Szent-Györgyi thinks that it is and that the same reasoning applies to human beings. It is not so easy with human beings as with guinea pigs to determine the "quantity of vitamin C naturally consumed," for after infancy human diets are influenced by too many factors ever to be called natural. But if a saturation dose for a guinea pig more nearly corresponds to the amount it gets daily from its simple natural diet than does the minimum dose which keeps it healthy only when it is not exposed to infections, it would seem that saturation doses for human beings might safely be used as requirements for optimal nutrition.

VITAMIN C REQUIREMENTS IN HEALTH

INFANTS

A perfectly healthy and happy breast-fed infant is presumably receiving an abundance of vitamin C from its mother's milk. The word "happy" is used because irritability is one of the first symptoms of lack of vitamin C in infants. Breast milk from healthy women on satisfactory diets has been shown in numerous tests reported from many countries to furnish from 4 to 7 or 8 milligrams of vitamin C per 100 cubic centimeters (about 3⅓ fluid ounces) during the first few months of breast feeding. Values below 4 milligrams indicate a very poor state of nutrition of the mother (*68, pp. 8–24*) and values above 8 milligrams are seldom obtained even when the mother is on a diet very rich in vitamin C.

Reported estimates of the amount of vitamin C breast-fed infants are actually getting have varied according to (1) the values within this range selected as corresponding most closely to actual conditions and (2) estimates of the volume of milk consumed, which can be determined only indirectly. The amounts range from 10 milligrams (during the first few days) to 50 milligrams of vitamin C a day received by the infant from the mother's milk. As already noted, the latter figure, which probably represents the best conditions, is equivalent to the amount of vitamin C in about half a cupful or 8 tablespoonfuls of orange juice.

How do these figures compare with recommended allowances of vitamin C for infants? As late as December 1937, the Technical Commission on Nutrition of the Health Organisation of the League of Nations recommended (*670*) from 5 to 15 milligrams of vitamin C daily as the requirement for artificially fed infants. This would correspond to about one-third of an ounce to an ounce (2 tablespoonfuls) of orange juice daily, a common recommendation in books on infant feeding.

It has recently been stated on good authority (*462*) that "the minimal protective dose of vitamin C for the average healthy infant is about 10 milligrams per day." As about 1 out of 20 of the more than 400 infants under observation in the study from which this conclusion was drawn was said to have had scurvy in a mild degree at some time or other during the several months of observation on a vitamin C intake approximating 10 milligrams daily, this allowance appears to offer little or no margin of safety and should be considered the irreducible minimum for protection against scurvy rather than the minimum for satisfactory health.

There is about as much difference between these recommended allowances and the amount of vitamin C a breast-fed infant under the best of conditions is getting as there is between the minimum protective dose of vitamin C for a guinea pig as established in laboratory tests and the amount a naturally fed guinea pig gets from its green food.

The generous estimates of the infant's vitamin C requirement based on the amounts received from mothers' milk are supported by some data from blood values and urine tests. Thus by several entirely different methods the vitamin C requirements for satisfactory nutrition of infants, not merely protection against scurvy, have been calculated to range from 20 milligrams (after the first few days when 10 milligrams may suffice) to a maximum at the end of breast feeding of about 50 milligrams daily; or on a weight basis, from 3 to 8 or perhaps within the smaller limits of 5 to 6 milligrams for every 2.2 pounds of body weight.

As the more liberal estimates are based on the amount of vitamin C furnished in the day's supply of breast milk of good quality, it is safe to say that the infant's requirement for vitamin C can be met by breast feeding alone provided the mother herself is taking a generous allowance of vitamin C. However, if her diet is deficient in vitamin C, the vitamin C content of her milk may be too low for safety.

This raises a question about pooled pasteurized mothers' milk, now being distributed rather extensively in the larger cities, and the various modifications or formulas for cows' milk.

Samples of pooled pasteurized mothers' milk as delivered to a hospital from a Directory for Mothers' Milk in one of our large cities were found to contain only 0.3 milligram of vitamin C per 100 cubic centimeters, or less than one-tenth as much as fresh breast milk of average quality (*572*). According to a recent compilation of vitamin values prepared in the Bureau of Home Economics (*255*), the vitamin C content of cows' milk ranges from 1 to about 2.6 milligrams per 100 cubic centimeters when pasteurized. It has been estimated (*499*) that by the time such milk has been diluted and modified for infant feeding, a day's supply of 600 to 750 cubic centimeters will furnish not more than 6 milligrams of vitamin C.

These figures would seem to afford evidence of the necessity of furnishing orange juice or some easily assimilable source of vitamin C to all artificially fed infants at a very early age, and the advisability of furnishing similar supplements to breast-fed infants when there is any doubt as to the quality of the breast milk. The United States Children's Bureau, in its most recent edition of Infant Care (*1208*), gives the following recommendations for vitamin C supplements in infant feeding:

> Orange juice (strained) or tomato juice or other source of vitamin C should be given to the baby before the end of the first month. The juices may be fresh or canned. Tomato juice may also be obtained by straining the pulp of fresh or canned tomatoes.
>
> If orange juice is used, begin with 1 teaspoonful a day. Gradually increase the amount until by the third month and thereafter 2 tablespoonfuls are given twice a day. Orange juice may be diluted with an equal amount of cool boiled water.
>
> If tomato juice is used, give twice as much as you would of orange juice. Begin with 1 teaspoonful twice a day and increase until by the third month 4 tablespoonfuls are given twice a day. Tomato juice is given without water.
>
> Grapefruit juice or lemon juice—but not prune juice—may be given instead of orange juice. Either fresh or canned juice may be used. Grapefruit juice and lemon juice are used in the same amounts as orange juice. They may be diluted with an equal amount, or more, of boiled water, and may be sweetened. Pineapple juice may be used. If fresh juice is used, give twice as much as you would give of orange juice; if canned, give three times as much. Pineapple juice need not be diluted.
>
> Occasionally fruit juices may cause some digestive disturbance. If it is certain that the disturbance is due to a particular fruit juice, another juice may be given, or, if the baby is breast-fed, juice may be omitted for a few weeks.

With 1 tablespoonful of orange juice furnishing about 7.5 milligrams of vitamin C, artificially fed infants given orange juice according to these recommendations will be getting vitamin C in amounts increasing gradually from 2.5 to 30 milligrams daily by the second or third month. The first solid foods given—cereal and egg yolk—at the fourth month will not furnish any additional vitamin C. The puréed vegetables and fruits added somewhat later will make a slight contribution, as will baked potato, but these solid foods are gradually introduced into the diet in such small amounts that they cannot be depended on to furnish much vitamin C. Banana pulp is often recommended in infant feeding, particularly in case of digestive disturbances. Recent studies (*682*) of the vitamin C content of bananas at the stage of thorough ripeness necessary for infant feeding have shown that a banana of average size furnishes from 6 to a little over 8 milligrams of vitamin C, or on the average about as much as 1 tablespoonful of orange juice.

Breast-fed infants who are given the same vitamin C supplement as infants artificially fed may be receiving more than 60 milligrams of vitamin C daily after the second or third month if their mothers are on diets furnishing an abundance of vitamin C. After weaning it seems likely that these infants may actually be getting less vitamin C than during the period of breast feeding, for the amount furnished by the solid foods will undoubtedly be considerably less than has been furnished by breast milk. If orange juice is well tolerated, it would seem logical to increase the allowance gradually to a total at about 9 months of 6 tablespoonfuls (3 ounces or a little less than half a cup) daily. This would furnish about 45 milligrams of ascorbic acid, an amount that still does not exceed what the infants may have been receiving from breast feeding.

CHILDREN

With the transition from breast feeding to a mixed diet it is no longer possible to estimate vitamin C requirements from food intake.

There have been very few studies of the actual requirements of healthy children based on any of the other methods described, although there are many reports on the vitamin C nutrition of healthy and sick children as determined by blood analyses and urinary output. The blood of children has the same range of vitamin C values as that of adults, and therefore the same standards apply. The output in the urine of healthy children depends directly on the intake.

From the rather small amount of evidence available, it would seem advisable to use the same optimum allowance for preschool children through the period of most rapid growth as for infants—that is, 5 to 8 milligrams for each 2.2 pounds of body weight.

In both infants and young children the minimum requirements as thus far established are only about one-fifth the maximum allowance or saturation requirement (regardless of whether or not the latter should be considered the requirement for optimal nutrition). With the infant the range is from 10 to 50 milligrams, with the preschool child from 22 to about 120 milligrams. For the preschool child a full measuring cup of orange juice would be required to furnish the entire quota of vitamin C, but this is not necessary, for with increasing variety in the diet other foods contribute a considerable share of the total supply. In the study (*350*) from which the very high figure of 120 milligrams was obtained, about one-tenth of the total vitamin C came from foods seldom considered as particularly good sources of this vitamin. Other foods might have been selected that would have furnished much more—quickly cooked young green cabbage in place of string beans, a dish of strawberries in place of some of the bananas, etc. It would have been possible to reduce the orange juice to half a cupful and furnish the rest of the vitamin in other ways. Again, the children in this study were presumably getting pasteurized milk. On the farm, milk may furnish a good share of the day's vitamin C allowance to children who are accustomed to drinking generous amounts of fresh raw milk, which may contain as much as 26 milligrams of vitamin C per liter (a little less than a quart).

ADULTS

For adults as well as infants and children the range in estimated requirements of vitamin C appears to be extremely wide—from 19 (*418*) to over 100 milligrams, or a fourfold to fivefold increase from the physiologically indispensable minimum to the maximum represented by complete saturation.[6] Between these limits various amounts have been recommended as standard allowances presumably representing requirements. The allowance of 30 milligrams daily as adopted by the Technical Commission on Nutrition of the League of Nations (*670*) seems dangerously near the physiological minimum on which close agreement was obtained by entirely different methods of approach. Even the frequently recommended allowance of 50 milligrams should probably be thought of as barely adequate, with no provision for individual differences in requirement and no margin of safety in case of illness or unusual demands.

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[6] In the Cornell University study referred to on p. 242 (*92a*) the saturation requirements for the 7 young people studied have ranged from a total of 70 to over 100 milligrams of ascorbic acid daily, or from about 1 to 1.6 milligrams per kilogram of body weight daily.

For those accustomed to taking a glass of orange juice or other fruit juices, grapefruit, or fresh berries in season as a matter of course at every breakfast, there is little danger that the total daily intake of vitamin C from all sources will furnish less than 75 or 100 milligrams daily. A small fruit-juice glass of orange juice furnishes about 50 milligrams, a full-sized glass or tumbler about 100 milligrams. Even without the use of oranges, it is comparatively easy to assemble a variety of foods in a day's diet that will furnish 100 milligrams or more, particularly if tomatoes, raw or canned, or tomato juice are used. But unfortunately individual food tastes are such that a surprisingly large number of American people do not take advantage of the abundance of vitamin C foods at their disposal, with the result that their day's intake may fall far below an allowance generous enough to provide for all demands.

For checking family diets, the number of servings of a few foods known to be particularly good sources of vitamin C is perhaps as good a guide as can be suggested. For this the table of values on page 289 is recommended.

Pregnant and Lactating Women

There is abundant evidence of a greatly increased need of vitamin C during pregnancy and lactation. A woman for whom a minimum requirement of 28 milligrams was established in the investigation of Widenbauer (*1217*) was found after becoming pregnant to need 71 milligrams daily in the third and 67 milligrams in the eighth month of pregnancy. The slight drop in the later period may or may not be of significance, but even the smaller of the two figures during pregnancy is more than twice the value for the same woman when not pregnant. In a similar study on a group of healthy women in the eighth and ninth months of pregnancy (*403*) values ranging from 33 to 64 milligrams were reported with the statement that not less than 100 milligrams daily should be considered as a safe allowance during this period.

This means that if a woman has been on a vitamin C allowance of about 50 milligrams daily, she would need to double this during pregnancy—for example, by changing from a small to a large glass of orange juice daily. If, however, she has been in the habit of drinking a large glass of orange juice daily, or taking equivalent amounts of other vitamin C foods, it will not be absolutely necessary to increase this during pregnancy. In other words, the margin of safety of the saturation allowance over the barely adequate allowance may be sufficient to carry her safely through the period of pregnancy, although even the saturation allowance will no longer be optimal.

In some instances it may be advisable to provide an additional margin of safety during this period even if it means taking some pure vitamin C in addition to food sources. Studies of the vitamin C in the blood plasma during pregnancy of two groups of women, one whose diets were carefully planned to provide an abundance of vitamin C and another of nearly the same number whose diets were not so carefully planned (*1124*), showed a decrease in the vitamin C content of the blood as pregnancy advanced, even in the women on diets uniformly high in vitamin C.

It is generally considered from observations on the vitamin C content of the blood of mothers and newborn infants that when the vitamin C requirements are not met in pregnancy the mother becomes depleted at the expense of the child, whose blood at birth is frequently considerably higher in vitamin C than that of the mother. The higher the content of vitamin C in the maternal blood the less is the difference between it and the blood of the newborn infant. As stated in a recent paper (*1124*):

> The fetus in utero acts parasitically on the mother with respect to vitamin C. So long as appreciable amounts of ascorbic acid are present in maternal plasma, the fetus tends to take what it needs irrespective of the maternal requirements.

During lactation the situation is somewhat different. Theoretically the complete vitamin C requirements of a nursing woman are met if she is able to produce milk of the highest vitamin C content possible and maintain a normal level of the vitamin in her blood, but if she receives too little vitamin C to meet both needs, the deficiency is likely to show first in a lowered content of the vitamin in the milk. Consequently, there are two ways of safeguarding against a deficiency of vitamin C in the mother and her breast-fed infant. One way is to add to the vitamin C allowance of adult women the calculated amount in a day's supply of breast milk of good quality. This additional allowance is estimated to be at least 50 milligrams daily. If the pregnant woman has been in the habit of taking a generous allowance of vitamin C, 100 milligrams or so daily, the additional 50 milligrams may not be necessary. The other way is to supplement breast feeding by giving the infant orange juice or some other easily assimilable source of vitamin C at a very early age. In view of probable differences in the ability of individual women to transfer vitamin C to their milk as well as differences in their own requirements for the vitamin, it would seem advisable to follow both means of safeguarding mother and child, that is, provide the mother with at least 100 milligrams of vitamin C daily and supplement the breast feeding by giving vitamin C to the infant.

Old People

With the general lowering of metabolism in old age it might be assumed that there would be a corresponding decrease in vitamin C requirements. There is some evidence, however, pointing to an even greater need of the vitamin—or at least to a greater use of it—in old age than in the prime of life. The old people who have thus far been studied (*407*, *481*) were in a state of unsaturation, as shown in the first study by the small daily output of vitamin C in the urine and in the second by the large amounts of vitamin C that had to be given before there was an overflow in the urine. As these old people were either hospital patients or inmates of an institution, it is not possible to state whether the unsaturation was the result of a greater natural need of vitamin C in old age or of a poor state of health with unrecognized infections.

The old people in the second study were living in an institution where the diet was considered good, great pains being taken to supply plenty of fruits and vegetables. However, following the treatment with pure vitamin C in the saturation tests, most of the subjects felt much better and were able to do more work. Although no attempt was made to determine the actual requirements of old people for vitamin C, a rough estimate was given of 50 milligrams in comparison with 25 to 32 milligrams for younger subjects studied at the same time. Greater significance should probably be attached to the relative than to the absolute values as suggesting a double allowance of the vitamin for old people. The low estimates for the younger subjects suggest that the investigators had in mind the minimum physiological requirement and that the 50-milligram estimate should be considered in the same sense.

If the margin of safety is considered in the double sense of a margin to cover variations in individual requirements and to meet unusual needs, it is quite probable that the saturation allowance of 100 milligrams for adults affords a safe margin for the additional needs of vitamin C in pregnancy, lactation, and old age, but that it is no longer a margin of safety to take care of unusually high individual requirements and the variations that are impossible to calculate in the vitamin C content of various items in the food supply.

REQUIREMENTS IN DISEASE

Vitamin C therapy has recently been described (*1240*) in terms of balancing a budget that has run into a deficit: "The deficit must first be determined, then it must be covered, and finally the budget must be kept balanced." While it is not yet possible to determine just why there should be a deficit of vitamin C in certain diseases or pathological conditions, there is abundant evidence in the medical literature that such a deficit does exist and that the extent of it can be measured by the same yardsticks of blood and urine analyses that have been used to determine the state of vitamin C nutrition in apparently healthy subjects. Moreover, it has been shown by the same methods that it is possible to balance the vitamin C budget in illness as well as health but that this usually requires much larger deposits, or daily allowances, of the vitamin.

To carry the analogy still further, the deficit of vitamin C in certain illnesses may not be due entirely to extra expenditures (increased use of the vitamin) but partly to lowered income (reduced intake) as the result of restricted diets. This was more often the case before vitamin C was known or its importance as a regular constituent of the diet was recognized—the days when sick people were told what not to eat instead of what to eat and physicians prescribed restricted diets to eliminate food constituents that were harmful in special diseases without realizing that in so doing they were producing a state of vitamin C deficiency.

The milk-and-egg diet for stomach ulcer as formerly prescribed without supplements is a good illustration of the use of a diet extremely low in vitamin C at a time when it is particularly needed to assist in the healing of the diseased tissues. Now it is considered that orange juice or tomato juice properly strained, and diluted if necessary, should be given as soon as possible for their vitamin C content. The proverbial gruels and the toast-and-tea diets of early convalescence with their complete lack of vitamin C illustrate failure to cover the deficit incurred during the illness.

Fortunately, with the present vogue for the generous use of fruit juices during illness and convalescence, diets at such times may be even richer in vitamin C than the customary diets in health. This is as it should be, for there is no question that a greater need results from an increased use of the vitamin by the body in ill health combined with a tendency toward a decreased food intake.

While it is beyond the scope of this article to discuss the vitamin C requirements in disease at any length, as this subject more properly belongs in medical journals where excellent reviews are to be found (*7, 911*), a few illustrations will be given of studies that have shown quite definitely a greatly increased need of vitamin C in certain pathological conditions.

GINGIVITIS AND PYORRHEA

The "pink tooth brush" slogan in popular advertising has done much to make people conscious of the disfiguring effect of a condition of the gums known as gingivitis, which causes bleeding at the slightest provocation. The word "pyorrhea" brings to mind the dreaded possibility of the loosening of teeth to such an extent that their removal is inevitable. Recent studies on both guinea pigs and human beings leave little doubt that the first defense against both of these conditions is an abundance of vitamin C.

Bleeding of the gums is one of the first symptoms of vitamin C deficiency to be noted in guinea pigs. This was described in the earliest mention of the condition brought about in guinea pigs by a diet lacking in green food (*1084*). A greater tendency to bleeding of the gums in human beings at some times than at others may well be due to marked changes in the vitamin C content of the diet, as in traveling in countries where fresh fruits are not to be had. In addition to such observations, which do not afford definite proof, there are case reports in the medical literature showing a relation between bleeding gums and low output of vitamin C in the urine, with cure of the condition and a return to higher values in urinary output following a marked increase in the vitamin C content of the diet. In one such case (*704*) improvement did not take place until the patient, a young woman, had been given 250 milligrams of vitamin C daily in the form of tomato juice and mixed citrus fruit juices. After 5 weeks on this diet the condition of the gums became normal and the output of vitamin C in the urine rose from very low values to approximately 30 milligrams daily, an amount within the normal range.

For some time interest in the changes in the inner structure of the teeth and in the soft tissues about the teeth in guinea pigs on diets deficient in vitamin C and the application of these findings to similar conditions in human beings overshadowed the more serious results of vitamin C deficiency in the bony structure holding the teeth in place. Recent studies on guinea pigs given graded amounts of vitamin C from traces up to enough for normal nutrition (*145*) have shown that in both acute and chronic vitamin C deficiency changes take place in these structures (the alveolar bone tissues) identical with those observed in human beings suffering from the more severe type of pyorrhea known as pyorrhea alveolaris (*146*). The extent of the changes in the guinea pig tissues depended upon the degree of vitamin

C deficiency. The identity of the conditions in guinea pig and man and its relationship to lack of vitamin C was further shown by the low blood levels of vitamin C in patients with pyorrhea of this type.

In discussing these studies and their significance at a dental society meeting (*144*), one of the investigators expressed the opinion that vitamin C deficiency is the only nutritional deficiency that produces the characteristic features of this type of pyorrhea in experimental animals and that in human beings vitamin C is essential to the maintenance of healthy oral tissues. He took pains to say, however, that vitamin C is not a panacea for all dental ills and in pyorrhea should be considered as a prerequisite and not a substitute for other treatment. His recommendation was that in such conditions blood determinations for vitamin C should first be made, and if a deficiency is found to exist it should be remedied by the administration of ascorbic acid before other treatment is instituted. But how much better is "an ounce of prevention than a pound of cure"! A liberal allowance of vitamin C in the diet at all times may be the means of preventing the necessity for the massive doses of the pure vitamin required after pyorrhea has been established.

STOMACH ULCERS AND WOUNDS

Stomach ulcers and wounds, including wounds produced in surgical operations, have been grouped together because the principle underlying the use of extra vitamin C as a therapeutic measure is the same—the ability of the vitamin to hasten reparative processes in the tissues either through its control of intercellular metabolism or through its oxidizing-reducing properties. Whatever may be the mechanism, the results are quite spectacularly demonstrated in guinea pig experiments.

In one such test (*413*) use was made of the property ascorbic acid has of reducing silver nitrate, which then forms a black stain. When the silver nitrate test is applied to various organs of guinea pigs, black granules appear wherever vitamin C is present. They are most abundant in glandular organs but are also found in muscle tissue and skin. When two groups of guinea pigs, one on vitamin C-deficient diets and the other on a normal diet reinforced with 100 milligrams daily of vitamin C, were given artificial wounds, the content of vitamin C in the various organs of the group on the diet low in the vitamin was very low and none could be detected in the skin and wound tissues, which showed little formation of new tissue. In the other group, which had received vitamin C far in excess of ordinary requirements, the content of the vitamin in the various organs was high, formation of new tissue in the wounds had taken place rapidly, and most significant of all, black staining of the granulations and adjacent skin showed the presence of vitamin C where the healing had been taking place.

Although there have been many suggestions of the probable value of extra vitamin C after operations, including particularly removal of the tonsils and tooth extractions, there are as yet few case reports on its use. Recently a case has been reported (*618*) of an operation on an infant in whom healing of the wound was apparently stimulated within 24 hours after the administration of a single massive dose (300 milligrams) of ascorbic acid by injection in the veins. In a review of a few other scattered cases the statement is made (*7*): "From the evidence presented one may conclude that vitamin C has an important role in the healing of surgical wounds. When a history of low vitamin C intake or a low plasma value is obtained preoperatively [before an operation], it would seem logical to administer vitamin C" both before and after the operation. These suggestions for the medical profession are quoted simply to illustrate one of the many advantages accruing from a regular intake of vitamin C considerably in excess of minimum physiological requirements, for under such conditions this special treatment might not be so necessary.

The existence of a vitamin C-deficiency state or, possibly, the increased use or disappearance of vitamin C in persistent cases of stomach ulcer has been proved in human subjects by the use of all three of the yardsticks of measurement already noted—the capillary-resistance test (*138*), output in the urine following test doses of vitamin C (*26*, *666*), and blood plasma values (*573*)—and by all of these tests on the same subjects (*932*). The general recommendation which has come from these studies is the liberal use of vitamin C in some easily assimilable form—prefaced, if necessary, by a few large doses of the pure vitamin to make up for the original deficit. This follows the rule cited at the beginning of this section of first determining the deficit, then balancing the budget, and finally keeping up the balance.

INFECTIOUS DISEASES

It seems fitting to end this discussion of vitamin C requirements by considering the effect of infectious diseases on requirements, for this takes us back again to the guinea pigs which 45 years ago in the laboratories of the Bureau of Animal Industry were killed by the inoculation of an amount of an infectious organism they should have been able to resist. Since that time there have been reports too numerous to mention of the lowered resistance to various infections of guinea pigs on diets deficient in vitamin C, and of lowered values in the blood content and urinary ouput of vitamin C in human beings suffering from a variety of infectious diseases.

In the most recent review available on this subject (*724*) rheumatic fever, pulmonary tuberculosis, diphtheria, and pneumonia are listed as infectious diseases in the prevention and cure of which vitamin C "undoubtedly plays a significant part," although "there is no unequivocal evidence that this nutrient has a *specific* role in the prevention or cure of any of them."

It is probable that the failure of intercellular substances to set to a jell in the absence of sufficient vitamin C accounts for lowered resistance to infections through breaking the first barriers of defense, as suggested earlier in this article. It is possible that the disappearance of vitamin C during the progress of infectious diseases accompanied by fever, as is usually the case, is due partly to the increased metabolism producing the rise in temperature. Evidence is increasing, however, that vitamin C does play an important part in the immunity defenses of the body and that increased allowances are necessary when these defenses are called into action to combat infections. The evidence is particularly strong in diphtheria, for it has been reported that in guinea pigs injected with diphtheria toxin the survival period was proportional to the amount of vitamin C the animals had been receiving (*630*); that when vitamin C and diphtheria toxin were mixed, the toxin after a time lost its strength and the vitamin was destroyed (*604*); and that when large doses of the vitamin—500 to 700 milligrams daily—were injected in the veins of human patients suffering from toxic diphtheria, little of the vitamin appeared in the urine (*886*). Although the only favorable effect noted as resulting from this large dosage of vitamin C in the human patients was on hemorrhages, particularly nose bleed, the evidence was thought by the reviewers (*724*) to suggest "unequivocally that ascorbic acid should be fed in generous amounts in diphtheria, as a means of preventing a deficiency of this nutrient in the tissues if not as a definite therapeutic measure."

The same conclusion might be drawn for pulmonary tuberculosis, a disease in the dietary treatment of which orange juice or tomato juice has long been used. Many studies have been reported in which low outputs of vitamin C were obtained in patients with pulmonary tuberculosis on diets which would ordinarily result in a fairly high output. In two such studies (*2*, *757*), when the cases were grouped according to the activity of the disease, it was found that the more active the disease the lower the output of vitamin C on a given intake. In the second of these reports an estimated 55 to 138 milligrams of ascorbic acid was given daily as the amount required "to bring a tuberculosis patient into equilibrium as regards vitamin C nutrition."

In a comparison of a small group of tuberculous and healthy children of the same age it was found (*170*) that the average daily output of vitamin C by the tuberculous children was only about 6½ milligrams and of the healthy children 30 to 35 milligrams.[7]

The examples cited are sufficient to indicate that the margin of safety furnished by the so-called saturation allowances in health may be none too generous to meet the greatly increased demands in certain pathological conditions.

SOME RECOMMENDATIONS BASED ON PRESENT KNOWLEDGE

There are many unanswered questions that make it difficult to give requirements for vitamin C with certainty. To quote again from the most recent edition of The Newer Knowledge of Nutrition (*724*):

> Adequate evaluations of ascorbic acid requirements are dependent upon objective methods of determining the health status in relation to ascorbic acid ingestion. Defects in the determination of either the health status or the amount of ascorbic acid ingested make it impossible to evaluate the requirements.

To these difficulties may be added lack of knowledge as to the fate of some of the ascorbic acid ingested. Does the difference between intake and output always represent the quantity used by the body in meeting its requirements for vitamin C? Obviously not in view of the instability of the vitamin and the wide ranges in values reported under conditions in which more constant results might be expected. Does saturation of the tissues represent optimal vitamin C nutrition? Though there are good arguments for answering this question in the affirmative, there is lack of agreement.

It seems reasonably certain, however, that the minimum and maximum values which have been reported may be considered to represent a range in allowances covering requirements from the physiologic minimum, which should never be lowered, to the optimum, the state of nutrition that cannot be bettered. For the various age groups these ranges between minimum and optimum appear to be as follows in terms of daily allowances:

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[7] When pure vitamin C was given to both groups in daily amounts of 50 milligrams per child, the highest average daily output reached by the tuberculous children was only 23 milligrams after 24 days during which a total of 1,200 milligrams of vitamin C had been taken by each child, while in the healthy group the average output rose to 70 milligrams on the 2d day after a total intake of only 100 milligrams.

Infants through the age of breast feeding (from birth to 9 months)—minimum, 10 milligrams; suggested optimum, 50 milligrams.

Children, 9 months to about 6 years—minimum, increasing gradually to about 20 milligrams; suggested optimum, increasing gradually to about 100 milligrams.

Older children—no data available; the allowances for adults are suggested.

Adults—minimum, 28–30 milligrams; suggested optimum, 100 milligrams or more.

Pregnant and lactating women—minimum, at least 50 milligrams over the minimum for other adults.

Elderly people—minimum, 50 milligrams.

For convenience in visualizing these quantities, some approximate equivalents of vitamin C and orange juice are repeated below:

Vitamin C	Orange juice
Milligrams:	
2½	1 teaspoonful.
7½	1 tablespoonful.
12½	1 fluid ounce.
50	½ cupful.
100	1 cupful.

In terms of body weight, allowances have been estimated to range from 3 to 8 milligrams per kilogram of body weight for breast-fed infants receiving no other supplements; about 7 milligrams per kilogram for maximum retention in preschool children; and from less than 0.5 milligram per kilogram for the physiologic minimum requirement to about 1.7 milligrams per kilogram for saturation in adults.

From these figures it may be assumed that the daily allowances should remain about the same in terms of body weight through the period of growth, and that the requirements for adults, although somewhat higher in total amounts than for children, are not more than one-fourth as much per unit of weight.

Allowances that are barely adequate for women should be increased by at least 50 milligrams daily during both pregnancy and lactation. Saturation allowances may provide sufficient vitamin C for these periods but with a decidedly reduced margin of safety to meet individual differences in requirement or unexpected losses.

Saturation allowances would seem advisable wherever possible because of the margin of safety they afford for emergencies of various kinds. Additional vitamin C in excess of the highest estimates for health may prove of great help after operations, in diseases involving damage to active tissues, and in infectious diseases.

VITAMIN D

by Frederick W. Irish [8]

VITAMIN D regulates the metabolism of calcium and phosphorus in the body, and thus is concerned in the proper formation of bones and teeth. The mechanism by which vitamin D functions has not been determined with finality, but it is believed that in some way it facilitates the absorption of calcium and phosphorus from the alimentary tract. It does not decrease the minimum requirement for calcium and phosphorus, however, and cannot produce good retention of these minerals in a person who receives too little of them.

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[8] Frederick W. Irish is Associate Chemist, Food and Drug Administration.

EFFECTS OF VITAMIN D DEFICIENCY

Because of the relationship of vitamin D to calcium and phosphorus metabolism it would be natural to expect the need for it to be most evident at that period of life when the formation of bone from the calcium and phosphorus of the food is in most active progress. This period occurs during infancy and early childhood, when the soft cartilaginous bones of the newborn infant are being converted into firm, hard bone and at the same time the skeleton is undergoing considerable linear growth; and it is at this age that the characteristic vitamin D-deficiency disease—rickets—develops.

This disease of infancy has in the past been very prevalent in this country, and it is still an ever-present menace to infants whose diets are not adequate with respect to calcium, phosphorus, and particularly vitamin D or its equivalent—adequate exposure to direct sunlight. For this reason the cause and treatment of rickets in infants have been the objects of intensive study by physicians and other interested scientists, and considerable information is now available regarding them.

In older children and adults the results of possible vitamin D deficiency do not manifest themselves in such a striking manner. As a result there has not been such an extensive study of the vitamin D requirements of these age groups, not only because the stimulus to carry on such studies was not as great, but also because definite criteria for determining the presence of vitamin D deficiency among individuals of these age groups do not exist.

SUBSTITUTION OF SUNLIGHT FOR DIETARY VITAMIN D

In discussing the dietary requirements for vitamin D it is always necessary to bear in mind that exposure of the body to direct rays of the sun serves the same purpose as the ingestion of vitamin D in the form of food materials or medicinal preparations.

A sterol, the precursor of vitamin D, is present in the skin, and probably in almost all animal tissues and cells, along with a related substance, cholesterol. In the presence of sunlight this sterol is activated, or forms vitamin D.[9] The antirachitic effect of sunlight is dependent on the intensity of the ultraviolet radiations in the light. This varies with a number of factors, prominent among which is the altitude of the sun above the horizon. This explains in part the greater incidence of rickets and the increased requirement for vitamin D from dietary sources during the winter and early spring, when the sun's altitude is low and in addition both the number of days of sunshine and the opportunity for exposure are likely to be restricted. The antirachitic effects of sunlight are decreased in the case of Negroes and certain dark-skinned white races, so that, unless they receive additional exposure to sunlight, the vitamin D requirement of such individuals is greater than that of lighter-skinned persons.

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[9] For footnote see facing page.

The extent to which vitamin D can be stored in the human body has not been investigated. However, evidence obtained from animal experiments indicates that vitamin D is stored to a considerable extent in the animal body, and if this is also true of human beings, it may be that vitamin D stored during the summer months, from exposure to sunlight when it is most potent, may exert a protective influence over a considerable portion of the year.

In other words, exposure to sunshine can replace a portion or all of the vitamin D that is required when this substance is obtained solely from dietary sources. In discussing vitamin D requirements and in planning studies designed to determine these requirements it is therefore essential that due consideration be given to this fact.

VITAMIN D REQUIREMENTS

The vitamin D requirements of infants given below were determined in studies made during the winter months when the influence of sunshine was at a minimum or under conditions that prevented exposure of the infants to direct sunshine. The limited data available with respect to older children were obtained under conditions permitting the exposure to sunshine normal for children of their ages.

In spite of the extensive work that has been done a certain lack of agreement still remains among authorities regarding the minimum vitamin D requirements of infants and young children. This arises in part from the use of different criteria in judging the adequacy of a particular vitamin D intake. Some investigators have used protection from rickets as the sole criterion, while others have combined this

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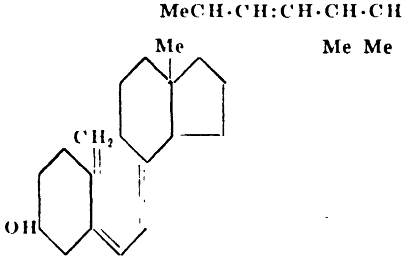
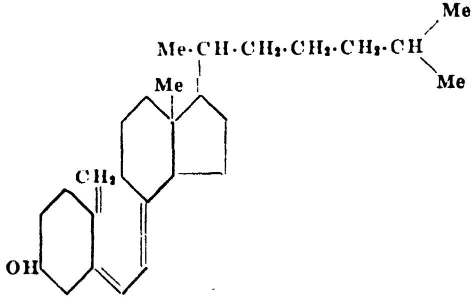
[4] There are several sterols which possess this property to a greater or lesser degree, but only two of them are at present considered of importance in connection with human nutrition. They are used to make two forms of vitamin D. One of these is prepared by the activation of ergosterol by treatment with ultraviolet light, or by other means, and has been called calciferol and also vitamin D_2. The structural formula of calciferol follows:



The other compound has been prepared artificially by the irradiation of 7-Dehydro-cholesterol, and such chemical studies as have so far been carried out indicate that this is the form of vitamin D that predominates in animal and fish oils. This compound is known as activated 7-Dehydro-cholesterol and as vitamin D_3. The structural formula of activated 7-Dehydro-cholesterol follows:



with other criteria, such as growth or the amount of calcium retained by the body.

The smallest amount of vitamin D that has been reported as effective in healing rickets in infants is about 90 U. S. P. (United States Pharmacopoeia) units[10] of vitamin D daily in the form of milk from cows fed irradiated yeast. However, the healing process with this vitamin D intake was much slower than when larger amounts were fed.

Another investigator reports 135 U. S. P. units daily of vitamin D from an animal source administered in milk as effective in preventing rickets in infants. This same investigator, however, recommends the administration of from 300 to 400 units daily to infants in order to assure proper growth and calcium assimilation.

An extensive clinical study involving the use of various sources of vitamin D, such as cod-liver oil, viosterol, and vitamin D milk, led to the conclusion that 675 U. S. P. units of vitamin D daily approximated the minimum protective level for infants under 1 year of age.

Other workers have interpreted the results of their investigations as indicating the daily vitamin D requirements for infants to be 300, 400, 450, and up to as much as 700 to 800 U. S. P. units.

It would appear after reviewing the above data that sufficient vitamin D to meet the requirement of infants will be insured by administering the average dose of cod-liver oil recommended in the United States Pharmacopoeia and by the Council on Pharmacy and Chemistry of the American Medical Association in the publication New and Nonofficial Remedies—that is, 2 teaspoonfuls daily. This amount of cod-liver oil of the minimum vitamin D potency required by law contains 624 U. S. P. units of vitamin D.

While the amounts of vitamin D discussed here are intended primarily for artificially fed infants, there are some authorities who believe that breast-fed infants should receive comparable vitamin D supplements. Others do not believe it to be necessary to supplement the diet of a breast-fed infant when the mother is receiving an adequate diet.

Premature infants probably require approximately twice as much vitamin D as full-term infants.

As already indicated, there are no definite criteria by which to judge the adequacy of vitamin D intake of older children and adolescents, and consequently knowledge of their vitamin D requirements is meager. Some investigators who have attempted to estimate the vitamin D requirements of older children by studies of growth and calcium retention have reached the conclusion that between 300 and 400 U. S. P. units of vitamin D daily are required, particularly during the season when exposure to direct sunshine is limited.

There is quite convincing evidence that an adequate intake of calcium, phosphorus, and vitamin D is of importance in connection with the prevention of dental caries (decayed teeth), particularly among growing children. Studies made on a large number of children in orphanages in and immediately adjacent to New York City with a view to determining the influence of vitamin D on the incidence of dental caries indicate that approximately 800 U. S. P. units of vitamin D daily are required to prevent an increase in the incidence of caries during the winter and spring periods. On the other hand, the children who were observed over a summer-vacation period during which no vitamin D supplement was supplied did not develop new caries to a significantly greater extent than did those receiving the 800 units daily during the winter and spring. This indicates that children of school age can receive adequate vitamin D effects from sufficient exposure to summer sunshine, even in large cities in the northern portion of this country where the intensity of the sun's rays is diminished by smoke and other forms of air pollution.

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[10] Vitamin D is measured with laboratory animals by means of bio-assays, which consist of comparisons of the activity of a substance with a known source of vitamin D. The results of these assays are expressed in units. One of the most widely used units, particularly in foreign countries, and to a considerable extent in this country, is the International Unit. The International Unit is defined as the biological activity of a very small quantity (0.025 microgram) of calciferol. The unit most widely used in this country is the United States Pharmacopoeia unit of vitamin D. This unit is identical with the International Unit, but as a standard of reference in determining vitamin D potency in these units a reference cod-liver oil is used that has been carefully standardized against the international standard calciferol.

The optimal vitamin D requirement for adults has not been determined. In fact, many authorities believe that it is unnecessary to administer this vitamin to adults other than pregnant and lactating women, for whom the League of Nations Health Organisation has recommended a diet and cod-liver oil supplement supplying somewhat more than 300 units of vitamin D a day. Other authorities have recommended that nursing women should receive at least 800 units daily. Aside from pregnant and nursing women, adults probably obtain sufficient vitamin D solely from exposure to sunlight. In any event, there is no concrete evidence to indicate that most grown persons, including indoor workers who have a minimum of exposure to the sun, suffer from vitamin D deficiency.

From this discussion it can readily be seen that any statement regarding human vitamin D requirements must be made with a number of qualifications, and that further information on this subject is much needed, particularly in regard to the requirements of adults. The following tabulation represents the best estimate of requirements that can be made on the basis of the information now available:

	Number of U. S. P. units of vitamin D daily
Infants:	
Artificially fed	300–800
Breast-fed	300–400
Premature	600–800
Children and adolescents	300–800
Adults	?
Pregnant and lactating women	300–800

VITAMIN E

by E. M. Nelson [11]

THE VITAMIN E requirement of man is not known. That the rat needs vitamin E cannot be questioned, but there is very convincing evidence that the goat will reproduce normally without vitamin E in its ration. Some clinical evidence suggests that certain cases of habitual abortion in the human species may be due to vitamin E deficiency but it has not been established beyond reasonable doubt that man needs this vitamin.

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[11] E. M. Nelson is Chief, Vitamin Division, Food and Drug Administration.

It has recently been reported that a substance having the properties of vitamin E has been synthesized in the laboratory, and it is believed that there are at least three closely related compounds having the same properties.

VITAMIN E NEEDS OF THE RAT

The use of the rat in nutrition studies has increased very rapidly during the past 50 years. As knowledge about various nutritional essentials developed, it became possible to use greater proportions of pure substances in experimental diets, and as these diets became more highly purified the need for certain substances could be demonstrated. About 20 years ago it was observed that rats fed highly purified diets frequently failed to reproduce even though their growth rate and general condition seemed to be entirely satisfactory. This observation prompted investigations to determine whether the rat required some particular substance in its food for successful reproduction, even though there was no known deficiency in the diet. Extensive study led to the discovery, about 15 years ago, that the rat will not reproduce unless its ration contains a substance which was subsequently named "vitamin E."

Vitamin E deficiency manifests itself in the rat by failure of the female to give birth to living young even though there appears to be no interference with conception and early growth in the uterus. Usually the young are not born but are resorbed in the uterus. This resorption begins a few days before the termination of the gestation period. In the male rat there are changes in the tissues of the testes, and the ability to produce living spermatozoa is lost.

The rat is used in determining the presence of vitamin E in foods, and the relative quantity can be determined with some degree of accuracy. Young female rats are fed a diet complete in all respects except for this vitamin. After a suitable interval of time they are bred with males of known fertility. The substance to be tested may then be given in a single dose or fed in desired amounts daily during the gestation period. The success of the females in producing living young when fed different quantities of the substance tested is a measure of the amount of vitamin E fed.

HUMAN NEED FOR VITAMIN E UNDETERMINED

It cannot be stated that because the rat needs vitamin E man also must have this vitamin in his food to assure successful reproduction. In studies conducted at the Iowa Agricultural Experiment Station, it has been possible to raise five generations of goats on a ration which by repeated tests on rats was shown to be free from vitamin E. Even the muscle tissue and milk from these goats were free from demonstrable traces of vitamin E, though the vitamin is readily shown to be present in the muscle tissue and milk of goats fed rations containing the vitamin. This seems to be satisfactory evidence that species other than the rat do not necessarily need to have this vitamin provided in their food.

Studies on human requirements for vitamin E have been confined largely to investigations of the effect of ingestion of wheat-germ oil in cases of sterility and habitual abortion in women. These studies indicate quite definitely that wheat-germ oil is of no value in the treatment of sterility. Habitual abortion has been defined as repeated abortions occurring in early stages of pregnancy. No reports have been published of clinical studies conducted in this country to determine the value of vitamin E in the treatment of habitual abortion. The papers that have been published in foreign journals indicate that wheat-germ oil was beneficial in approximately three-fourths of the cases of habitual abortion that were treated. It seems fair to state that the interpretation of these investigations is rather difficult because of the lack of a precise control of the variable factors in such clinical studies. Of further importance in applying these observations is the fact that the number of cases of habitual abortion is very low.

A review of the literature published to date leads to the conclusion that it has not been definitely established whether or not man requires vitamin E, though there is some evidence indicating that this vitamin may be needed. If the occurrence of habitual abortion is taken as a criterion of vitamin E deficiency, the number of cases of actual deficiency must be very small. If this vitamin is needed by man, it is found in so many of the foods generally consumed in this country that a deficiency is not likely to occur.

RIBOFLAVIN

by Lela E. Booher[12]

Riboflavin is now the generally accepted name for the water-soluble, yellow-pigmented vitamin that occurs in a wide variety of natural foods. In years past this vitamin has been designated by a number of different names, including lactoflavin, vitamin G, and vitamin B_2—the last by English and German investigators. "Flavin" is derived from the Latin word "flavus," meaning yellow; the ending "in" implies that these yellow pigments contain nitrogen. The prefix "ribo" (or "d-ribo") identifies riboflavin as a particular member of this class of pigments that contains also the residue of a particular sugar, d-ribose.

DISCOVERY OF THE VITAMIN, RIBOFLAVIN

The first scientific account (*131*) of the water-soluble yellow pigment in milk appeared in 1879. Not until almost 50 years later did this pigment again receive scientific consideration. Its more obvious properties were described in 1925 (*128*), but its real significance remained obscure until about 5 years ago.

Independently and almost simultaneously, in 1933, American (*134*) and European (*316*, *651*)[13] investigators announced the discovery of the biological significance of this pigment.

Early attempts to rear animals on a diet of purified protein, fat, carbohydrates, and inorganic salts met with complete failure. But if to this diet were added small quantities of milk whey and butterfat, the animals began almost immediately to grow and to show every appearance of being well nourished. It required nearly 20 years of active research before it became known that the water-soluble yellow pigment in whey was one of the vitamins that contributed to the successful rearing of animals on a simplified diet.

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[13] Reference (*316*) was published in Germany in February; reference (*651*) in Germany in April; reference (*134*) in North America in September.

Step by step the proteins, lactose, fats, and inorganic salts in whey were eliminated, leaving at each step a product more intensely yellow and more concentrated in vitamin activity (*134*). Riboflavin was first isolated in pure crystalline form from egg whites by Kuhn and his coworkers (*651*). Isolation of riboflavin from milk and many other plant and animal sources quickly followed as a result of the work of many investigators.

Success in recognizing the vitamin activity of the whey pigment was greatly favored by increased knowledge of other vitamins necessary for growth and well-being. As an abundance of other vitamins was added to simplified diets in concentrated forms, the need for the water-soluble yellow pigment of whey stood out in bolder relief. Young albino rats receiving adequate quantities of all the other vitamins necessary for growth except riboflavin begin to lose hair around the eyelids, which gives them a spectacled appearance. The loss of hair progresses until often the animal is almost entirely denuded. Meanwhile the skin, particularly on the paws, ears, nose, and around the mouth, becomes inflamed and swollen—a condition known as dermatosis—and sooner or later the tips of the toes darken, become very dry, and drop off at successive joints. Addition of very small quantities of riboflavin to a diet adequate in other respects promptly restores growth, produces a thick, sleek coat of hair, and cures the dermatosis.

PROPERTIES OF RIBOFLAVIN

Crystals of riboflavin are yellow-orange in color and form needle-shaped clusters as the alcohol is evaporated from an alcoholic solution of riboflavin (fig. 3, *A* and *B*). Many concentrated solutions of riboflavin exhibit a bright-yellow color, and at the same time some of the light illuminating them becomes a bright green. If light of short wave lengths only (ultraviolet light), which the eye does not see directly, is used to illuminate riboflavin solutions in a darkened room, this green coloration is very pronounced. This so-called fluorescent property, which enables a substance to absorb light and change its color, is characteristic of riboflavin. Addition of either acid or alkali to a water solution of riboflavin decreases the intensity of its green fluorescence.

The vitamin activity of riboflavin is gradually destroyed by exposure to ordinary light, which also causes its yellow color to disappear. Many chemicals also reduce the color of riboflavin and destroy its vitamin activity.

High temperatures, particularly in the presence of alkalies such as soda, destroy the vitamin activity of riboflavin.

Figure 3.—*A*, Crystalline riboflavin (×200). (Photomicrograph courtesy of Lincoln T. Work, Columbia University.) *B*, Riboflavin crystallized from 2 normal acetic acid solution (×175).

A
B

Riboflavin is soluble in water, dilute acids, and alcohol, but not in fats nor in most of the liquids used to dissolve fats.

DISTRIBUTION IN FOODS

Riboflavin is widely distributed in nature. It has been isolated from milk, egg white, egg yolk, liver, kidney, barley malt, yeast, dandelion blossoms, and grasses.

Muscle meats all contain riboflavin. Dark meat is richer in riboflavin than white meat. Many animal organs such as liver, kidney, and heart are richer in riboflavin than is muscle tissue.

Almost all fruits and vegetables contain some riboflavin, but the richest plant sources are the green leafy types of vegetables such as turnip greens, spinach, carrot tops, and kale.

Milk, cheese, whey, and eggs are important sources of riboflavin. Butter contains only the riboflavin carried by the curd, which, in view of the small quantities of curd in butter, is not of any significance.

The fresh and dried legumes and whole cereals, relatively large quantities of which make up the bulk of many diets, provide significant quantities of riboflavin. Certain types of soybeans appear to be excellent sources. Riboflavin is unequally distributed in the grains, being richer in the germ and bran portions than in the endosperm. Wheat germ, for example, is four or five times richer in riboflavin than is the whole grain. Highly refined cereals, like most other highly refined foods, are unimportant sources.

QUANTITATIVE DETERMINATION IN FOODS

The actual quantities of riboflavin in even the richest natural food sources are extremely small, but viewed from the standpoint of nutritive needs these small quantities assume great importance.

Fluid milk contains not more than 1 part of riboflavin in 600,000 parts of milk; yet milk is one of the most important sources of this vitamin in a well-balanced diet. Its importance as a source of riboflavin in children's diets is even greater.

Because of the minute quantities of riboflavin in foods, special methods for determining these quantities have had to be developed. Methods strictly chemical in nature are in process of being developed. One of these involves the measurement of the intensity of the green fluorescence of riboflavin in concentrated extracts. It is very difficult, however, to obtain all of the riboflavin in a given food in a watery extract. Besides this difficulty, it seems probable that other food constituents associated with riboflavin may interfere with the fluorescence measurements.

Biological tests involving the use of suitably standardized small animals must in the end determine the acceptability of any chemical or physical test for riboflavin in foods. Most of the data on the riboflavin values of foods have been accumulated by the biological assay method. This method (*139*) is based primarily upon the principle of supplying to young rats a diet adequate in all nutritive essentials except riboflavin until their growth ceases. When the animals have reached this stage, weighed supplements of the food under test is administered daily in such quantities as will promote a standard rate of growth or a rate of growth equal to that produced by a standard quantity of pure riboflavin. The amount of food under test which promotes this rate of growth can then be said to contain as much riboflavin as the standard quantity of pure riboflavin.

Because all the vitamins necessary for growth and well-being are not yet known and are not available in pure form or even in highly concentrated extracts free of riboflavin, serious difficulties are presented in preparing a diet adequate in all respects except for riboflavin. A thoroughly satisfactory method for determining the riboflavin content of foods depends in large measure upon increased knowledge of unidentified vitamins essential for growth and well-being.

THE PHYSIOLOGICAL FUNCTION OF RIBOFLAVIN

Some years ago Warburg and Christian (*1180*) described an enzyme obtained from yeast cells which was concerned in cellular oxidations. This enzyme is frequently referred to as "Warburg's yellow enzyme." Its discoverers credit it with being present in every living cell. It later became evident that riboflavin is a component of this yellow enzyme, in which it is combined with phosphoric acid and a protein similar to albumin. It is assumed, therefore, that riboflavin is essential to the animal organism in order that this enzyme may be formed to take part in the energy metabolism of the body.

That riboflavin is intimately concerned in life processes is further indicated by the fact that certain organs of animals (liver, kidney,and heart) and the green leaves and germ portions of plants are comparatively rich in riboflavin. These tissues of animals and of plants are those in which the most active chemical changes take place.

In view of the widespread distribution of riboflavin in foods of both animal and vegetable origin, riboflavin deficiency in man is probably not very frequent. Severe deficiencies of riboflavin in man have, however, been described recently by Sebrell and Butler (*1021*). Judging from their description the inflamed and scaly condition of the skin around the corners of the mouth, at the base of the nose, and on the ears appears to be very similar to that frequently observed in experimental animals deprived of riboflavin.

If a diet containing a fairly wide variety of common foods is consumed in quantities sufficient to provide adequate amounts of the other known food essentials, there would appear to be little danger of an inadequate intake of riboflavin. Sherman (*1048*) has shown in experiments with animals that successively more liberal amounts of riboflavin in the diet, up to about four times as much as needed to prevent the first sign of riboflavin deficiency, results in increased positive health. Probably human diets that include a wide variety of natural foods provide a liberal margin of riboflavin.

THE CHEMICAL NATURE OF RIBOFLAVIN[14]

The chemical structure of riboflavin has been established beyond any doubt. Kuhn (*653*) and Karrer (*608*), together with their respective coworkers, independently achieved the synthesis of riboflavin in 1935.

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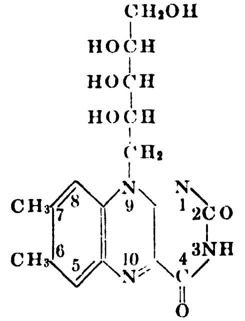
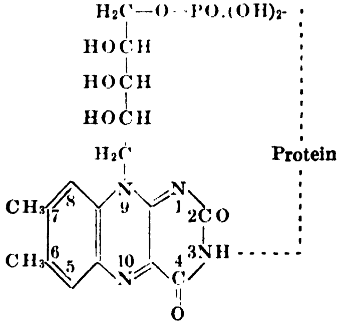
[14] This section is intended primarily for students and others especially interested in the purely scientific aspects of nutrition.

The accepted structural configuration for riboflavin is shown here:



Although only one flavin appears to occur in nature, several compounds closely related to riboflavin but possessing less biological activity have been synthesized. The tricyclic chromophore nucleus is common to all flavins (those occurring naturally in foods and those made synthetically); the position and kind of substituent groups attached to the benzene ring and the nature of the side chain attached to the nitrogen atom in position 9 are determinate factors for vitamin activity. In riboflavin both the substituent groups in positions 6 and 7 are methyl groups, and at least one of these is essential in synthetic flavins in order that the molecule shall possess vitamin activity. As regards the side chain, only d-ribose or l-arabinose residues attached to the nitrogen atom in position 9 have thus far proved to be compatible with vitamin activity. In the case of riboflavin the side chain is a d-ribose residue.

The yellow enzyme is formed by a combination of riboflavin, phosphoric acid, and a protein, presumably an albumin. This enzyme may be represented graphically by:



Further information on the chemical aspects of riboflavin will be found in a recent review article by Booher (*135*).

THE PELLAGRA-PREVENTIVE FACTOR

by O. L. Kline[15]

THE DISEASE called pellagra has been known for a long time. Its cause has been variously ascribed to infection, to toxins, and to dietary deficiencies, but recent nutritional research has eliminated the first two of these as causative agents and has demonstrated the complete preventability of pellagra by means of diet. Pellagra occurs most often among poor people. The disease has a high incidence in Egypt, the Balkan countries, the Soviet Union, Italy, Spain, and the United States. In Egypt 30 percent of the population have been known to be affected, and in the United States as many as 400,000 cases annually have been reported. It has been stated that 10 percent of the inmates of the asylums in the southern part of the United States have been admitted because of their pellagrous condition.

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As early as 1912 it was suggested by Funk (*401*) that pellagra is caused by a deficiency in the diet of one of the substances that he named "vitamines." Two years later the classical researches of Goldberger and his associates (*423*) at the United States Public Health Service were begun with the aim of determining the cause of the disease and the cure. Goldberger and his group spent a number of years working with pellagrous patients in some of the southern institutions, and as a result of this work they were able to state that pellagra may be completely cured and prevented by a change of diet. Goldberger was able to demonstrate which of the foods tested contained the pellagra-preventive factor, and these foods were tabulated (*1019*) on the basis of their value in preventing the disease.

It was noted by these investigators (*424*) that the disease called canine blacktongue occurred in dogs maintained on diets similar to those that were known to produce human pellagra. A further important contribution was the demonstration that blacktongue in the dog corresponds to pellagra in man—that is, the two diseases are true analogues. This gave research workers an invaluable experimental method for the evaluation of the pellagra-preventive factor in foods, as well as a method that helped in the chemical isolation of the pellagra-preventive factor.

During the past 5 years this work has progressed rapidly, and Elvehjem and coworkers (*327*) announced in 1937 the isolation of nicotinic acid and nicotinic acid amide from concentrates known to prevent blacktongue in dogs. It was further demonstrated (*328*) that these chemical compounds will cure and prevent blacktongue. A number of clinicians, notably Spies and associates,[16] Fouts and coworkers (*380*), Harris (*1089*), and Smith, Ruffin, and Smith (*1065*), have demonstrated that nicotinic acid is effective in the treatment of human pellagra.

SYMPTOMS OF PELLAGRA

Pellagra is a disease with a long developmental period, and for this reason may become complicated with dietary deficiencies other than a deficiency of the pellagra-preventive factor, particularly those of vitamin B_1 and riboflavin. Pellagra may be associated with measles, typhoid fever, or other infectious diseases, but it is due primarily to the absence from the diet of a specific nutritional factor. It is therefore a noncontagious disease characterized by a group of symptoms affecting particularly three systems of the body, the dermal system or the skin, the gastrointestinal or digestive system, and the nervous system. The disease is characterized by seasonal recurrences and relapses and may occur in persons of any age or race. It was observed in the past that the disease occurred principally among groups of people whose diets contained large amounts of maize or maize products, and for this reason it was thought to be caused by moldy corn. It was also noted that pellagra occurred in persons who were directly exposed to the sun's rays, and therefore sunlight was thought to be a causative agent. These views, however, are now known to be entirely erroneous.

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[16] SPIES, T. D., COOPER, C., and BLANKENHORN, M. A. THE USE OF NICOTINIC ACID IN THE TREATMENT OF PELLAGRA. Read before the Central Society for Clinical Research, Chicago, Nov. 5, 1937.

The onset of the disease is so gradual that the earliest symptoms may not be noticed by the patient. Loss of strength in the legs, a change in appetite, a loss in body weight, and a change in mood or personality are the most usual early symptoms. Changes in the skin do not always occur, but when observed they take the form of symmetric lesions on any portion of the body, though most commonly over the sites of irritation, that is, the hands, wrists, elbows, knees, and feet. There is a sharp line of demarcation between the affected area and the healthy skin. The lesion begins as a redness or erythema similar to sunburn; then the area becomes reddish brown, roughened, scaly, and horny. Intensity of pigmentation and thickening of the skin increase with each recurrence of the disease.

The first noticeable symptoms in the digestive system are inflammation of the tongue and linings of the mouth and throat. Later the tip and the margin of the tongue become swollen and red, deep ulcers developing along the side and the tip, with intense swelling. The linings of the mouth and the stomach are similarly affected, causing burning sensations. Lack of hydrochloric acid in the stomach (achlorhydria) is not uncommon, and severe diarrhea invariably occurs in acute cases.

Symptoms involving the nervous system are commonly nervousness, dizziness, headache, and numbness or paralysis in the extremities. In advanced cases there may be degeneration of the spinal cord, resulting in spasmodic movements (spasticity) and loss of coordination (ataxia). Periods of mental depression and apprehension are experienced, and hallucination, confusion, delirium, and complete disorientation may develop. In the absence of treatment the patient is likely to become insane.

THE FUNCTION OF NICOTINIC ACID

Conditions similar to the pellagra symptoms are known to occur in other species of animals. On certain deficiency diets rats develop an inflammation of the skin (dermatitis) that is suggestive of human pellagra. This condition may be cured by the administration of vitamin B_6. A pellagralike group of symptoms has been produced in chicks on experimental diets. Crude concentrates prepared from liver and from yeast have been used to cure the four conditions, human pellagra, canine blacktongue, rat dermatosis, and chick dermatosis.

As purification of these concentrates proceeded it was found that vitamin B_6 could be removed by adsorption on fuller's earth (*102, 680*). After further purification Elvehjem and coworkers (*327, 328*) were successful in isolating a crystalline substance, which they identified as nicotinic acid amide and with which they were able to cure canine blacktongue. The dogs so cured were maintained in a normal condition for a considerable length of time. This same compound, nicotinic acid amide, was found to be ineffective, however, in the pellagralike condition of chicks. Elvehjem and others (*1271*) have very recently announced that a substance having properties similar to those of pantothenic acid—a compound known to be a growth stimulant for micro-organisms—is specific for the cure of this type of dermatosis in chicks.

It remained for the clinicians to demonstrate the effectiveness of nicotinic acid amide in the cure of human pellagra. This substance has now been used in the treatment of a large number of cases of the disease. The curative effect is a dramatic one, with all of the swelling, dermatitis, mental depression, and digestive disorder relieved in a few days. This result has been corroborated by a number of workers, and that nicotinic acid or its amide is a primary factor in the cure and prevention of pellagra is now well established.

The function of this substance in the body, although still not well defined, has been suggested by the fact that it is present in certain of the coenzymes—substances necessary for the activity of enzymes. One of these, cozymase, is a compound made up of nicotinic acid, adenine, phosphoric acid, and a sugar called ribose. These coenzymes are necessary in the body to aid in the transfer of oxygen from the blood to the tissues for the oxidizing or burning of food substances, with the resulting release of energy. In the absence of nicotinic acid these coenzymes cannot be synthesized by the body and normal metabolism of food substances is interfered with. Spies and coworkers (see footnote 16 for reference) have reported that the blood of normal persons contains considerably more cozymase than the blood of pellagrous patients and that pellagrins' blood was increased in its cozymase content after nicotinic acid therapy.

PREVENTION AND CURE OF PELLAGRA

Pellagra, like other dietary deficiency diseases, is most effectively prevented by adequate diet. Although many satisfactory results are obtained in mild cases when diet changes are made to include corrective foods, nicotinic acid should be indicated as a curative agent in most cases of the disease.

Values for the content of the pellagra-preventive factor in foods as determined by Goldberger and associates in well-controlled experiments and adapted by Sebrell are given in table 1 (*1020*).

It will be noted that yeast, milk, wheat germ, lean meats, green vegetables, and legumes are the most effective foods in the treatment of pellagra. Mild cases of the disease may be effectively treated by using a diet of 3,000 to 4,000 calories daily containing lean meats, liver, or other foods rich in the pellagra-preventive vitamin, in addition to milk.

Goldberger and Tanner (*422*), who first used yeast in the treatment of pellagra, found that 1 gram per kilogram of body weight was an effective supplement. Later it was determined that 30 grams of dried brewers' yeast was sufficient to cure experimental pellagra while patients were maintained on a deficient diet. It is probable that yeasts vary in their content of the pellagra-preventive factor, but 1 to 2 ounces of the dried powder should prove effective in the cure of most pellagrous patients. A smaller amount would suffice as a preventive measure.

Human requirements for the specific curative substance, nicotinic acid, are not known with certainty. The use of nicotinic acid has made more evident the fact that human pellagra is due to a multiple deficiency. The polyneuritis occurring in some cases of pellagra has responded to administration of vitamin B_1. Dogs maintained on the Goldberger diet are known to develop a riboflavin deficiency (*1023*). A lack of this factor may be responsible for some of the changes in the nervous system that are found in human pellagra cases of long standing.

TABLE 1.—*Pellagra-preventive value of foods* [1]

Food	Quantity	Pellagra-preventive value	Food	Quantity	Pellagra-preventive value
Cereals:	*Grams*		Vegetables:		
Corn meal, whole, white	450	None.	Beans:	*Grams*	
Cornstarch	366	Do.	Green, stringless, canned	550	Slight.
Oats, rolled	400	Do.	Kidney, red	360	Fair.
Rye meal	400	Do.	Navy	360	None.
Wheat germ, ether extracted	150	Good.	Soybeans	360	Fair.
Wheat, whole	400	Slight.	Cabbage, green, canned	482	Do.
Dairy products:			Carrots	450	Slight.
Butter	135	Do.	Collards, canned	482	Good.
Casein, leached	85	Do.	Cowpeas	178	Fair.
Egg, yolk, dried	100	Fair.	Kale, canned	534	Good.
Milk:			Lettuce, cos, canned	516	Slight.
Buttermilk	1,200	Good.	Mustard greens, canned	533	Fair.
Evaporated, canned	(2)	Fair.	Onions:		
Skim, dried	105	Do.	Green, canned	502	Slight.
fresh	(3)	Do.	Mature	525	None.
Fruits:			Peas:		
Apples, evaporated	250	None.	Green, canned	450	Good.
Prunes, dried	250	Do.	Green, dried	360	Fair.
Meats and fish:			Potatoes	450	None.
Beef:			Sweetpotatoes	450	Do.
Corned, canned	200	Good.	Spinach, canned	482	Fair.
Fresh, lean	200	Do.	Tomato, juice from canned	1,200	Good.
Chicken, canned	325	Do.	Turnip greens, canned	482	Do.
Haddock, canned	340	Fair.	Turnips, rutabaga	453	Slight.
Liver, pork, dried	64	Good.	Miscellaneous:		
Pork:			Cottonseed meal	200	Do.
Salt, fat	153	None.	Gelatin	83	None.
Shoulder, lean	200	Good.	Liver extract (Minot's 343)	(4)	Fair.
Rabbit	184	Do.	Peanut meal	200	Good.
Salmon, canned	168	Do.	Rice polishings	400	Do.
Oils and fats:			Yeast:		
Butter (*see* dairy products).			Bakers', dried	30	Do.
Cod-liver oil	128	None.	Bakers', dried, autoclaved	60	Do.
Cottonseed oil	110	Do.	Brewers', dried	30	Do.
Lard	110	Do.	Yeast vitamin powder	15	Do.

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[1] This table, reprinted from the Journal of the American Medical Association (*1020*), by permission, was adapted from Table Showing the Pellagra-Preventive Value of Various Foods (*1019*). It is intended primarily for use in the treatment and prevention of pellagra, and only those foods are included which have been tested under controlled conditions in either human beings or dogs or both. In the absence of a quantitative method of assaying the pellagra-preventive vitamin, only the most general terms can be used to designate the pellagra-preventive value of a food. In order to make a division into groups which will be of practical value without being unwarrantedly exact, the words "good," "fair," "slight," and "none" have been selected. The quantity used must be kept in mind in each instance, since smaller amounts than those indicated would in all probability have less value. "Good" signifies that the indicated quantity of food contained enough of the pellagra-preventive factor to prevent the disease. This is the most valuable class of foods in the prevention and treatment of pellagra. "Fair" signifies that the indicated quantity of food showed appreciable and in some instances considerable pellagra-preventive value, but 1 or more of the experimental subjects developed the disease, usually after considerable delay. Thus, a food under this heading contains enough of the vitamin to be of value but should not be relied on alone in the treatment and prevention of the disease. The principal value of these foods lies in the variety of items afforded as adjuncts to the good sources of the preventive factor. "Slight" signifies that the indicated quantity of food, although failing to prevent the disease, caused a slight delay in onset. Practically, this group may be disregarded in the treatment and prevention of pellagra. "None" signifies that, in the quantity used, the results of the experiments indicate that the food contains either none of the preventive factor or such a small amount that it may be regarded, for practical purposes, as being entirely without value in the treatment and prevention of pellagra.

[2] 15 cc. per kilogram of body weight.

[3] 30 cc. per kilogram of body weight.

[4] Equivalent to 100 gm. of liver.

Ruffin and Smith (*992*) have stated that pellagra is the result of two or more deficiencies. Recent results indicate that pellagrins maintained on daily administrations of nicotinic acid show a return of the disease unless the size of dose is steadily increased. All these complicating factors make it virtually impossible to estimate the human requirement for this substance with any accuracy. Sebrell and associates (*1022*) have shown that 1 milligram a day will just suffice to prevent blacktongue in dogs on a deficient diet. Other workers have estimated that 1 milligram per kilogram of body weight daily is the amount required by the dog. Curative doses used for human patients have varied from 50 to 500 milligrams, and the usual curative dose now used is 300 milligrams daily. This gives little indication of the daily requirement for good health, however. Such information will be more readily obtainable when other as yet unknown factors have been identified.

It may be said in summary that human pellagra is a disease of dietary origin, having widespread occurrence. A large number of cases occur annually in the southern part of the United States, particularly among the poorer classes of people. Recent findings indicate that nicotinic acid amide is the chemical substance in which these diets are primarily deficient. Secondary deficiencies of vitamin B_1 and riboflavin are also likely to occur. The symptoms of pellagra are dermatitis, digestive disorder, and changes in the nervous system. Nicotinic acid has a dramatic effect in curing all these symptoms. A change of diet to include foods known to contain the pellagra-preventive factor is also essential in the permanent cure and prevention of pellagra. Human requirements for the pellagra-preventive factor are not accurately known. Such values can only be determined when all factors involved in this disease have been identified.

FOOD COMPOSITION

by Charlotte Chatfield and Georgian Adams[1]

FOOD-COMPOSITION tables are the basis for all dietary calculations, and they are used to determine the adequacy of existing diets as well as to devise better ones. The tables summarize facts patiently collected over many years from hundreds of scattered sources. Here is an account of what information they give, how they are made up, and what their shortcomings are. The article also includes lists of foods rich in three minerals of major importance—calcium, phosphorus, and iron.

ON THE BASIS of studies to determine the body's requirements for energy, proteins, minerals, and vitamins, standards may be formulated for guidance in planning our diets or in evaluating our food habits. Before these requirements and standards can be translated into actual practice, however, we must know what foods supply the essential nutrients.

To this end, food-composition data are necessary. This implies that the foods themselves must be analyzed to determine their content of moisture, protein, fat, carbohydrate, calcium, phosphorus, iron and other minerals, and the several vitamins as well. This involves an enormous amount of detailed work, and it has taken many years to bring our knowledge of foods to its present state. A great many analysts working in various laboratories throughout the country have bontributed to this knowledge, but even now the study cannot be considered complete. As a step beyond the analytical work, the analyses from these hundreds of sources must be assembled, evaluated, and finally summarized in tables for convenient reference.

The importance of definite knowledge of the chemical composition of foods has long been recognized. The first analyses of American foods were made as long ago as 1844, when Shepard determined the mineral constituents of Indian corn and sweetpotatoes (*1036*),[2] and of rice, rice flour, and other rice products (*1035*). In subsequent years many foods were studied by workers in various laboratories, and in 1896 Atwater and Bryant (*51*) published an extensive compilation on the proximate composition—the term commonly used for an analysis that is approximate, or not complete in all details—of American food materials. Their tables, giving figures for the moisture, protein, fat, carbohydrate, and ash (mineral) content of a great many foodstuffs, summarized the data on American foods on record up to July 1895. They included in addition many unpublished analyses made in connection with nutrition investigations and other studies.

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[2] Italic numbers in parentheses refer to Literature Cited, p. 1075.

Our knowledge in the field of nutrition has greatly increased since those tables were published, and emphasis in diet practice has shifted from mere calorie counting to consideration of adequate protein, mineral, and vitamin intake, but data on the foods themselves are still basic to dietary plans.

In fact, the Atwater and Bryant tables, known to many as Bulletin 28, have been a standard of reference ever since their publication. Tables in many texts on foods and in dietetic manuals have been based in rather large measure on these early figures. These values are still fairly representative, particularly for the natural unprocessed foods that have not significantly changed in composition with the development of new varieties and new cultural methods. Within more recent times new summary tables on the proximate composition of fresh fruits and vegetables (*200*, *201*) have been issued by the Department of Agriculture. These are largely based on analyses since 1900 and supersede the corresponding sections in the Atwater and Bryant compilation, confirming or modifying their data and providing in addition figures for many fruits and vegetables not included in their list.

Actually, of course, foods are variable in composition, and no two tables based on different sets of analyses will be exactly alike. For a given kind of food there will be variations depending on such factors as variety and maturity differences, climate, storage, and nature of the analytical sample. Thus, juice from Concord grapes contains on an average about 16 percent of sugar, while that from raisin grapes averages about 25 percent. Young, green sweet corn averages about 5 percent of sugar and 9 of starch. As the corn matures the starch content increases rapidly, so that fresh corn that has arrived at the stage designated as old may contain as little as 2 percent of sugar and as much as 26 of starch. In potatoes stored at temperatures below 40° or 50° F., there is a conversion of some of the starch into sugar, while fresh corn and peas held at room temperature rapidly lose their sweetness as sugar is used up in the respiratory process. These few examples serve to illustrate how the composition of a single food may vary. Moreover, if natural foods are subjected to processing, further variations will be introduced.

Since foods are not constant in composition it is customary in many food tables (references *51*, *200*, and *201* are examples) to report the maximum and minimum values found for each food as well as the averages. These maximum and minimum values do not represent the actual limits of variation which can occur, but merely the range in composition in the particular samples studied. They serve to tell the reader that the food is variable, and that the average does not necessarily give the exact composition of any particular sample. The average serves, however, as a working estimate of the composition of the food.

In actual practice food tables are used in making calculations to determine the nutritive value of the diet as a whole or in determining what the individual foods contribute to the diet. For example, the nutritionist may want to determine how much protein, how much calcium, how much of the other minerals, and how much of the vitamins a given population group is getting according to its dietary habits; the dietitian may need to plan a diet that will furnish just so many calories and contain so many grams of carbohydrate, protein, and fat; and the layman may need to know merely in a general way what foods can be relied on as good sources of the various minerals and vitamins.

It is not necessary either for diet calculations or for general information on relative food values to know how variable in composition each food may be, but it is essential to have for all foods representative average values that will provide a reasonably good basis for calculations. Such averages or general estimates of the proximate composition and fuel value of a great number of common foods have been summarized in convenient form for publication.

Tables that have been compiled cover practically all classes of foods and extend to many items not included in the earlier bulletins. Many of the values reported are the same as those in the older tables, but many others are newly derived. This is particularly true for processed foods, for which new figures were needed in line with present-day standards and processes. The data given cover the gross or proximate composition of foods, that is, their moisture, protein, fat, carbohydrate, and ash content, and their fuel or calorie value. Tables of proximate composition do not give such details as the kinds of protein present in a food, the quantities of different minerals, or the vitamin content.

WHAT FOOD-COMPOSITION TABLES CONTAIN

Moisture is a constituent of all foods and represents essentially the amount of free water present. It is determined as the amount of substance lost in drying the material under specified conditions of analysis. That which is not moisture constitutes the "solids" and is made up of protein, fat, carbohydrate, and ash. Thus fresh fruits contain 75 to 90 percent of moisture, the remainder being chiefly sugar. Certain leafy vegetables such as beet greens, spinach, or lettuce may contain as much as 90 to 95 percent of moisture, and certain fruit forms such as tomatoes, summer squash, and cucumbers are also largely water, averaging about 95 percent. Fluid whole milk, however, averages only 87 percent of moisture, since it has measurable amounts of protein, fat, and sugar held either in true solution or in fine suspension. At the other extreme, dry beans and peas, cereals, and nuts have a moisture content of 5, 10, or 15 percent, and such foods as sugar and lard contain almost no moisture. The moisture contents of other foods lie between these extremes.

Proteins, unlike carbohydrates and fats, characteristically contain the element nitrogen. It is customary, therefore, to determine the total amount of nitrogen in a food, and then to multiply this by an appropriate factor, such as 6.25, which gives a working estimate of the total amount of crude protein. Other factors than 6.25 are sometimes used, depending on the type of protein present.

The food tables show that our richest sources of protein are cheese, meats, eggs, certain nuts, and dry legumes. Within this group the protein runs from 10 to 35 percent. Cereals are the next richest source of protein, while the fresh fruits and vegetables, except for beans and peas, contain about 1 percent or less. The figures for crude protein, however, express only the total amount of protein present and give no indication of its quality, that is, the efficiency with which it meets the body's needs.

Fats are soluble in ether, and the fat content of foods is determined, therefore, as the portion extracted by ether. The term "ether extract" is sometimes used in place of fat. Data indicate that the vegetable oils and lard stand at one extreme of fat content, being 100-percent fat, while fresh fruits and vegetables, with a few exceptions, are at the other extreme, containing less than 1 percent. Avocados and olives are exceptions among the fruits; certain kinds of avocados contain as much as 25 percent of fat and the usual ripe pickled olives about 19 percent. Among the vegetables, dry soybeans average about 18 percent of fat. Nuts as a group are rich in fat, the content varying from 33 percent in coconuts to 70 or more in pecans. Meats are exceedingly variable in fat content, the amount being determined chiefly by the fatness of the entire animal and by the way it is cut and trimmed.

Aside from moisture, protein, and fat, carbohydrate is the only other constituent of foods that may occur in large quantities. Here again, however, the amount varies, from 100 percent or nearly that in purified sugars or starches down to negligible amounts in meats. Several kinds of carbohydrate occur in foods. Sugars, dextrins, and starches, forms of carbohydrate readily utilized by the body, are of chief importance. Crude fiber, on the other hand, represents the indigestible residue from plant foods; it is not present in any of the animal foods. "Total carbohydrate by difference" is usually reported in food tables and represents the solids left after deducting protein, fat, and ash. The term includes organic acids and any undetermined solids as well as carbohydrate. Sugar, starch, and fiber are often reported separately, thus giving information about the nature of the carbohydrate present.

The amount of mineral matter in foods is indicated in a general way in the tables by the component designated as ash, the material left after the organic portion is burned away. From the nutritional standpoint, values for total ash are not so important as data on the individual mineral elements, such as calcium and iron, for example, which need special consideration in diet plans.

For the constituents other than minerals, average values in published tables give a basis for making fairly good estimates of the quantities present in the total diet. Such estimates cannot be exact because of variations in the composition of foods, but for practical purposes they do very well when the diet is taken as a whole.

MINERAL CONTENT OF FOODS

Dietary estimates for minerals are much less satisfactory than those for other constituents because of the limitations of present knowledge concerning them. Calcium, phosphorus, and iron have been studied more than other elements because of their known significance as measures of the adequacy of the diet, and information about them, though meager in comparison with that on proximate composition, is of first importance to nutritionists. Enough is known to indicate what foods are especially good as sources of each of these elements, and also to indicate that diets are frequently too low in one or more of them. From the information at hand it is possible to plan diets that contain safe allowances of the minerals, even though the estimates of the quantity in any given food are relatively crude approximations.

FOODS RICH IN CALCIUM

The foods regarded as excellent or good sources of calcium are listed below. If they were placed in the order of importance, milk in its various forms (other than butter) would head the list of common foods, and green leafy vegetables would rate among the next best.

Excellent

- Amaranth
- Broccoli
- Buttermilk
- Cabbage:
  - Savoy and nonheaded
  - Chinese, nonheaded varieties including tendergreens
- Chard
- Cheese:
  - American or Cheddar
  - Swiss
- Clams
- Collards
- Cress, garden
- Dandelion greens
- Kale
- Milk, whole or skimmed; evaporated, condensed, and dried
- Molasses
- Mustard greens
- Orach
- Sesame seed
- Tendergreens
- Turnip tops
- Water cress

Good

- Almonds
- Artichoke, globe or French
- Beans, common or kidney, dry or fresh, shelled; also snap or string

Good—Continued

- Burdock, roots
- Cabbage, headed, especially green
- Carrots
- Celeriac
- Celery
- Cheese, cottage
- Chickpeas, whole
- Chicory, leaves
- Cottonseed flour
- Crabs
- Cream
- Eggs, whole
- Egg yolk
- Endive or escarole
- Figs, dry
- Kohlrabi
- Leeks
- Lettuce, head or leaf
- Lobster
- Maple sirup
- Okra
- Oysters
- Parsnips
- Romaine
- Rutabagas
- Sorgo sirup
- Soybeans, dry or as green vegetable
- Soybean flour
- Sweetpotato tops
- Turnips
- Vegetable-oyster or salsify

Certain plant foods, the calcium content of which was high enough to justify inclusion in this list, have been omitted because of their oxalic acid content. Beet greens, dock, rhubarb, spinach, and New Zealand spinach were left out on this account. If a food contains enough oxalic acid to combine with all of its calcium to form calcium oxalate, the evidence seems to show that the calcium is of little or no use to the body. This may be because the calcium oxalate is already formed in the food; or it may be that the oxalic acid combines with calcium during or after digestion, making it insoluble so that the body cannot utilize it. These same foods, of course, may be valuable for other elements than calcium.

FOODS RICH IN PHOSPHORUS

There is a longer list of foods rich in phosphorus, and more food classes or groups are represented. Nearly all of the calcium-rich foods contain significant quantities of phosphorus, and in addition lean meats, fish of all kinds, and several other classes of foods are rich in this element. All animal tissues except fat contain liberal quantities, and many grain products are among the better sources. The following list, though far from complete, will suggest that choosing a diet with enough phosphorus should be comparatively easy:

Excellent

Barley, whole
Beans:
  Common or kidney, dry, shelled
  Lima, fresh or dry
Brazil nuts
Buttermilk
Cheese, Swiss
Cottonseed flour
Cowpeas, or black-eye peas, shelled
Crabs
Eggs, whole
Egg yolk
Fish
Liver, any kind
Lobster
Meats, lean or medium fat, having more than 12 percent of protein
Milk, whole or skimmed; evaporated, condensed, and dried
Oysters
Poultry
Rice bran
Rice polish
Sesame seed
Shrimps
Soybeans
Soybean flour

Good

Almonds
Artichokes, globe or French
Bamboo shoots
Barley, pearled
Beans, mung, dry
Broccoli
Brussels sprouts

Good—Continued

Buckwheat flour
Cashew nuts
Celeriac
Cheese:
  American or Cheddar
  Cottage
Chickpeas
Clams
Cocoa
Collards
Corn, green, sweet
Corn meal, whole ground
Cress, garden
Dasheen or taro
Hazelnuts and filberts
Kohlrabi
Lentils
Meats, fat, having more than 6 percent of protein
Millets
Oatmeal or rolled oats
Orach
Parsnips
Peanuts
Peas
Pecans
Pistachio nuts
Rice, brown
Rye flour
Walnuts
Wheat:
  Flour, graham or whole-wheat
  Shredded or puffed
  Whole grain or meal
  Bran
  Germ

FOODS RICH IN IRON

Meats, egg yolks, and green leaves are the foods most often accented in lists of iron-rich foods. Whole-grain cereals, although they are not as high in iron, are among the most useful sources because they can provide much of the necessary iron in low-cost diets that have very limited quantities of the more expensive sources. All of the foods in the following list are regarded as rich sources.

Excellent

- Apricots, dried
- Beans:
  - Common or kidney, shelled
  - Lima, shelled, fresh or dry
- Beet greens
- Broccoli leaves
- Chard
- Cowpeas, shelled, dry or fresh
- Dandelion
- Eggs, whole
- Egg yolks
- Heart
- Kale
- Kidney
- Lentils, dry
- Liver
- Meats, lean or medium fat (beef, veal, pork, or lamb), over 15 percent of protein
- Molasses
- Mustard greens
- New Zealand spinach
- Oysters
- Peaches, dried
- Poultry, especially dark meat
- Shrimps
- Sorgo sirup
- Soybeans, dry or as green vegetable
- Spinach
- Tongue
- Turnip greens

Excellent—Continued

- Water cress
- Wheat bran

Good

- Barley, whole
- Beans, snap or string
- Brains
- Broccoli
- Brussels sprouts
- Cabbage greens or outer leaves
- Collards
- Corn meal, whole ground
- Dates
- Dock or sorrel
- Endive or escarole
- Figs, dried
- Leaf lettuce
- Meats, fat (beef, veal, pork, or lamb), over 10 percent of protein
- Oatmeal or rolled oats
- Peas, green or dried, whole seeds
- Poultry, light meat
- Prunes, dried
- Rye flour, whole
- Seedless raisins, or "currants"
- Sugarcane sirup
- Vegetable-oyster or salsify
- Whole-wheat cereals
- Whole-wheat flour

OTHER MINERALS IN FOODS

Numerous mineral elements other than calcium, phosphorus, and iron are required by the body. Some of them, including sodium, potassium, and magnesium, occur in fairly large quantities in foods—that is, in quantities comparable to those of calcium and phosphorus. A fair number of mineral analyses of foods cover these elements, but no summary of these analyses has been made in the Department of Agriculture nor is any contemplated at the present time. This is partly because these elements occur so commonly in foods that nutritionists question whether any freely chosen diets of human beings are deficient with respect to any of them, and partly because authentic analytical data are even more meager for them than for calcium, phosphorus, and iron.

Copper, because of its established nutritional importance, has been determined in a variety of foods. It has been found to occur in measurable amounts in all or nearly all of the natural foods studied. The quantities are very small, barring contamination from spray materials used in combating plant diseases or from industrial sources. Enough is present naturally, however, so that the likelihood of a deficiency of copper seems rather remote except on very restricted diets in areas where the soil is poor in this element and the bulk of the food supply is produced locally. Such a deficiency may occur in sections where the livestock are subject to the condition known as salt sick, but this has not been established.

Cobalt has only recently been recognized as an element of which a deficiency in the diet may be serious. Only very minute quantities are needed. The effect of such a deficiency in the ration of sheep and cattle is mentioned in the article on Mineral Needs of Man (p. 215). It is remotely possible that in some areas of the world, possibly some in the United States, cobalt deficiencies in human diets may exist; but it seems improbable that freely chosen diets will fail to provide enough of this element unless they are very poor in several other respects.

Manganese is another mineral element for which the body apparently has need. The need is very small, however, and there is no evidence that diets are ever deficient in this element. As a matter of fact, in experimental studies with animals it was found exceedingly difficult to prepare diets that would be free from manganese. Although there have not been many quantitative studies on the amount of this element in foods, the results show that it is widely distributed, occurring in fruits and vegetables, nuts and grains, milk, animal organs, and other foods. Nuts and seeds, including all the cereal grains and the legumes, seem to be among the richer sources.

Zinc is probably necessary in minute amounts in human nutrition, but the evidence on this point is meager. There is little or no danger of a deficiency of this element, since it seems to be present in trace amounts or more in a wide variety of foods.

Various studies have shown that arsenic often occurs in human tissues. On the other hand it is known that only very small amounts of arsenic can be tolerated without toxic effects. In a survey made a few years ago to determine the amount and distribution of arsenic naturally occurring in foods, a great many samples were analyzed. Practically all classes of foods were examined, and it was found that arsenic was much higher in sea foods than in any other class, barring of course those carrying spray residues. Even in the marine products, however, the quantities are so very small that, at the most, arsenic as it occurs naturally in foods can be considered only a trace element.

Chlorine, chiefly in the form of chlorides, is present in relatively large amounts in almost all foods. In addition, table salt, which is sodium chloride, is added freely to our diet.

Iodine is necessary for the proper functioning of the thyroid gland. It is needed in only very small amounts, but unless special provision is made, even these small quantities are often lacking in the diets of people living inland in certain areas where iodine is deficient in the soil and the water. Plants grown on these soils are very low or even altogether lacking in iodine. Foods grown or raised in coastal regions, on the other hand, generally contain more iodine than those grown inland, and in some cases they may even be rich in this element. In coastal areas the soils and the water contain more iodine, and the plants in turn absorb more. In foods of animal origin, such as eggs and milk, for example, the iodine content depends upon the amount of iodine received by the animal either in natural feed or forage or in the form of special iodine supplements to the ration. In general, then, foods cannot be listed as good, fair, or poor sources of iodine, since actually the iodine content does not depend upon the kind of food, but rather upon the locality where it is grown, if it is a plant food, or upon the iodine supplied to the animal if it is a food of animal origin. The one exception to this is the sea foods, such as marine fish and shellfish. These are always rich in iodine, obtained from the sea water.

So little is known at present about the need for bromine, or its occurrence in foods, that any discussion would necessarily be unsatisfactory.

Sulfur, while very necessary to the animal body, is generally not considered in connection with the mineral elements in nutrition. This seems logical when it is considered that sulfur plays its important role in the body, not in the form of an inorganic substance but in complex organic compounds. Moreover, practically all of the sulfur obtained from food is in organic combination, chiefly as a constituent of proteins. If the diet contains sufficient protein of the right kind, this element will be furnished in adequate amounts.

Fluorine, boron, and silicon are found in the body but there has been no evidence to indicate that they are really necessary for the physiological functioning of the animal organism. Their occurrence in foods has not, therefore, assumed particular importance from the standpoint of nutrition.

Carbon, hydrogen, and oxygen are never given consideration as individual elements in studies on foods. They do not occur separately, but only in combination in complex organic compounds—the proteins, fats, and carbohydrates. Foods, therefore, are not analyzed for these elements. Nitrogen, of chief importance as a constituent of proteins, is likewise not regarded as a mineral element.

SHORTCOMINGS OF MINERAL ANALYSIS

Compilations showing the quantities of the more important mineral elements in many of the common foods have been published (*152*, *519*, *1048*), and numerous publications give data from a limited number of original analyses. Such tables are in wide use for diet calculations. It is plain that quantitative values are to be preferred to such simple classifications as have been presented here. But the data now available on this subject are far from satisfactory, for several reasons.

In the first place, many of the existing analyses were made by methods now known to give erroneous results. When such data are discarded, too few findings remain, except for a very few foods, to give satisfactory estimates. Fewer authentic analyses have been made for these constituents than for moisture, protein, carbohydrate, fat, and ash, whereas more analyses are required if the resulting averages are to be equally good.

The number of determinations should be greater in the case of the minerals, because variations due to the variety and kind of a certain food material and differences in sampling or preparation of the food for analysis frequently affect the minerals much more than they influence the total solids, protein, or carbohydrate. It is clear that with wider variations more observations are needed to provide equally good determinations of the average composition.

Existing data also fall short of present needs because of the character of the materials that have been studied and the design of the experimental work. Many of the analyses on which averages in such compilations are based, perhaps the majority of them, were made for other than dietary purposes, and the food samples often were not well chosen from the standpoint of nutrition. When analyses are made in connection with studies in agronomy, plant or animal physiology, food inspection or control, or industrial investigations, the materials selected for analysis are apt to be quite different from samples that would be chosen in an experiment designed for deriving average values for use in diet calculations.

A good example of the need of careful discrimination in making food analyses can be given in the case of common cabbage. The percentage of calcium in dark-green cabbage is many times higher than that in white, but most authors in publishing results of analysis of this vegetable have failed to tell whether any or all of the dark-green outer leaves were left in the part sampled. Those who do give this information usually neglect to state the variety of cabbage, or to what extent the inner part was bleached.

Evidence to show how much better the greener leaves are as a source of calcium is given in a more technical discussion at the end of this article (p. 283). From the chemist's or nutritionist's standpoint the data available are nevertheless inadequate except to give crude estimates of the average quantity in the several kinds of cabbage that are consumed. There is enough evidence, however, to warrant advising consumers to watch for greenness in picking out cabbages at the market and to see that some of the bright-green outer leaves are left with the lighter-colored inner part in preparing cabbage for the table. It is worth while mentioning here that the vitamin A and the iron as well as the calcium content are higher in the green leaves.

Another vegetable that shows wide variations in calcium content is the soybean. In this case the variations are associated with variety and with maturity, and probably to some extent with the soils on which the plants are grown. On the average, green vegetable soybeans have enough calcium to rate as good sources of that element, but the individual variation is so wide that some of the specimens analyzed would count as excellent and others would fail to rate even as good, according to the criteria on which the list of calcium-rich foods was prepared. The degree of variation is shown in the more technical part of this article.

Most other natural foods probably vary similarly in their mineral content, but even less is known of the mineral constituents of the majority of them than of the calcium in cabbage and soybeans. Highly refined foods like sugar, patent flour, and cooking fats, all low in minerals, are probably less variable in their mineral content; but manufactured foods that contain more minerals are usually less standardized as to processes and formulas, and may vary in mineral content even more widely than the natural foods.

In view of this variability in composition it must be plain that tables on the mineral content of foods should be based, not on a few scattered analyses of poorly described specimens of each item listed, but on well-planned chemical investigations. Better analytical data are needed so that the mineral estimates in food-composition tables will give a more nearly correct means of determining whether a particular diet is satisfactory.

For nutrition purposes, moreover, it is not enough to know how much of each of these elements is present in the food materials. Chemists are now being called on not only to give the quantity of calcium or of iron in different substances but also to supply information that will throw light on the availability of these elements to the body. The relationship between calcium and oxalic acid, already mentioned, is a case in point. More information is needed on the oxalic acid in foods because of its bearing on calcium metabolism. There may be other calcium compounds in foods besides oxalate that the body cannot absorb or metabolize, but so far the chemist has been asked to account only for the total amount of calcium, not to say in what form it exists in the food.

Phosphorus compounds in foods also are dissimilar in their availability to the body. Some work has been done toward finding what kinds of compounds are available and devising chemical methods for distinguishing between them as they occur in foods. Information on this problem, however, is not of first importance from a dietetic standpoint, because nutritionists believe human beings rarely suffer for lack of phosphorus unless the diet is so bad that several other nutrients are deficient at the same time. Other food-composition problems that are far more urgent have prior claims on the chemists' attention.

Iron compounds are by no means alike in their value to the body. Some, the soluble inorganic compounds, are generally admitted to be effective nutritionally while others, complex organic compounds like hematin, are known to be almost if not completely inert. Chemists are attempting to develop methods that will distinguish available iron from iron that the body cannot use, but their efforts so far have not been entirely successful. No one denies that a determination of total iron in a leafy vegetable, for example, may be a very poor measure of the iron that vegetable will contribute to the body. Some progress has been made toward determining what part of the total iron is present in available form in a number of food materials, but much more chemical work in this direction is needed, and to accomplish the end in view, it must be performed in connection with biological experiments.

It has been established by means of experiments with laboratory animals that the quantity of total iron in a good many foods is not a measure of their value as a source of iron to the body. This method usually consists of feeding weighed quantities of the food under investigation as a supplement to the ration of rats first made anemic on a milk diet, and observing the rate of gain in hemoglobin that follows. It has been shown by several investigators that the gains on particular foods are significantly slower than they would be if all of the total iron were physiologically available. This indicates the need for further work to establish satisfactory chemical methods.

Further discussion of this subject from a more technical standpoint follows.

TECHNICAL NOTES ON MINERAL ANALYSIS[3]

CALCIUM IN CABBAGES

The differences in calcium content between inner and outer leaves of cabbage, as shown in figure 1, are wide enough to merit careful consideration by chemists and nutritionists. The variations in calcium are shown in this chart as relatively wider than either those in solids or those in total ash. In fact, the variations in calcium are so great that a logarithmic scale is necessary to show the values for green and bleached leaves in proper perspective. The unshaded area represents the frequency of analyzed samples that were more or less bleached in the cases that were described, or assumed to be bleached in those reported only as "cabbage." Included with these samples are five from red or violet-colored cabbages which on inspection did not appear to differ materially in calcium content from the white or nearly white kinds. The shaded area represents the frequency of analyzed samples that were either dark-green outer leaves or leaves of the nonheaded samples. In the upper distribution, based on calcium, it will be noted that the mean of the standard area is eight or nine times the mean of the unshaded and that the extreme is more than 20 times the lower mean.

The similar distributions based on solids and on ash show that there are distinctions between dark-green and bleached leaves in these constituents too; but here the degree of variation is not nearly so great. Attention is called to the position of the two samples of savoy cabbage which, so far as we know, are the only ones of this variety that have been analyzed as the inside portion of the head. This variety is light green in color throughout the head, possibly because it is not tightly headed. At any rate it is not white or completely bleached, and there are several varieties other than savoy which are like it in being loosely headed and light green to the center of the head. The assumption is that other varieties that resemble savoy in color will be similar in calcium content, but actual evidence on this point is lacking.

If calcium, even more than total solids or total ash, is associated with greenness, it seems obvious that a comparison between varieties that are white inside and savoy, as well as other kinds that are light green, should be made in the analytical laboratory. The light-green headed kinds would be distinctly superior, it seems, as sources of calcium, but chemists, horticulturists, and physiologists apparently have not recognized this as a problem; none of the analyses of cabbage made incidentally to their problems has provided a direct answer to the question.

CALCIUM IN SOYBEANS

A study has been made of the available data on calcium variations in immature soybeans, that is, in the green-vegetable stages of certain varieties that agronomists and home economists have selected as suitable to use in this way. This study, based chiefly on the work of two laboratories (*1261*),[4] covers 78 samples, the majority of which are on 11 varieties picked at intervals during ripening. The investigations on this vegetable are better designed in several respects than those on most foods, and the results here admit of drawing some generalizations. According to these data it appears that varietal and other differences in calcium are so wide that they tend to obscure the changes associated with advancing maturity, but the latter are by no means insignificant.

Results on the entire 78 samples give an average of 0.074 percent of calcium (0.034 to 0.109 percent) on the fresh basis and 0.251 percent of calcium (0.161 to 0.356 percent) on the dry basis. Chemists usually prefer the dry basis on the ground that the dry substance is more nearly constant in composition. The deviations are not quite so wide, relatively, in the data on the dry basis as on the fresh, but even at best these variations are fully as wide as those in total solids on the fresh basis. Total solids average about 30 percent and range from 16 to 38.

Varietal differences are probably chiefly responsible for the wide variations in calcium content as expressed on the dry basis, although maturity has some effect and soil differences and other factors not yet studied may also play some part. The data indicate that as the seed matures the total solids and the calcium on the fresh basis increase rather steadily, while the calcium on the dry basis decreases somewhat. Thus the younger, more succulent seeds, having less than 30 percent of solids, average 25 percent of solids and 0.068 of calcium, while the older seeds average 34 percent of solids and 0.080 of calcium in the original material. This

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[3] This section is intended primarily for students and others technically interested in nutrition.
[4] Unpublished data on the work of the second laboratory furnished by W. J. Morse, Bureau of Plant Industry.

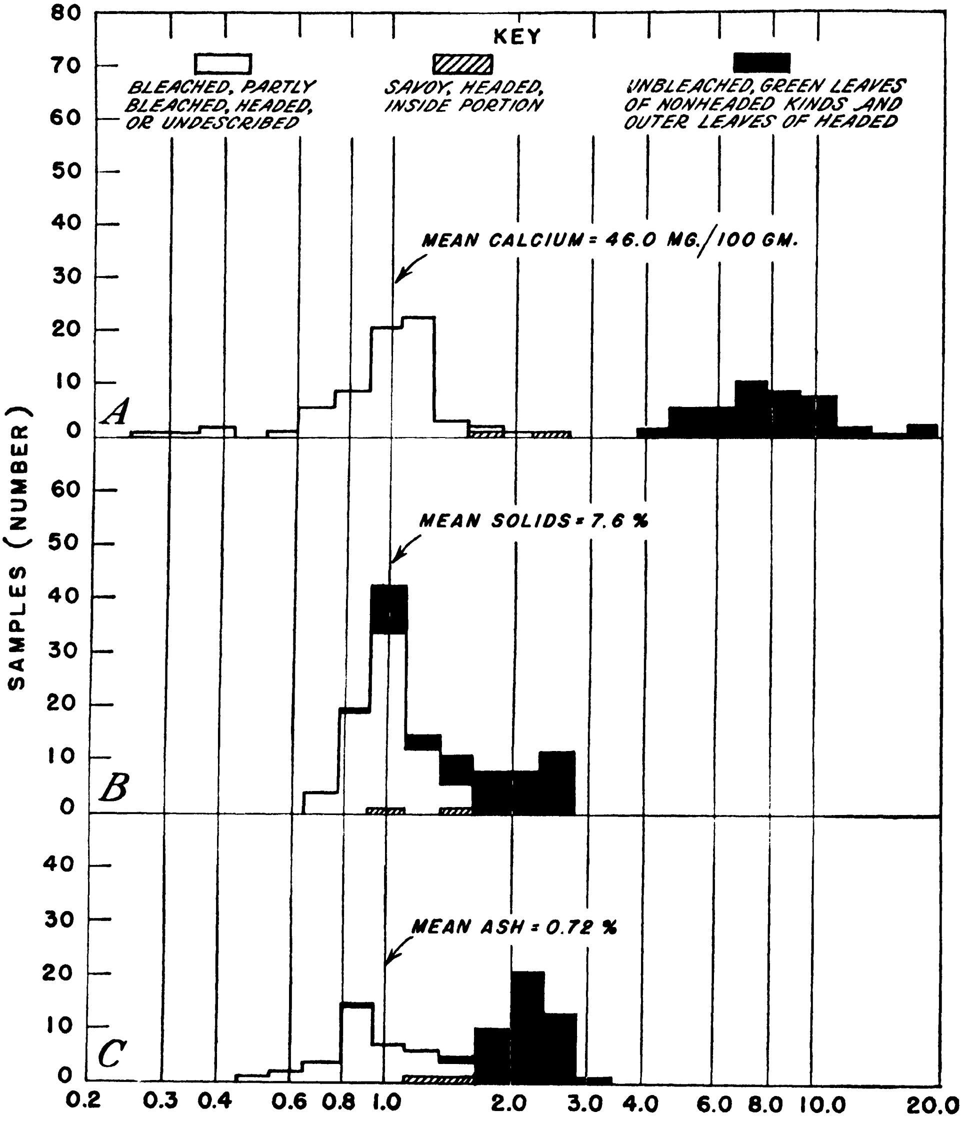

Figure 1.—Frequency distributions showing calcium (*A*), solids (*B*), and ash (*C*) o. bleached and unbleached samples of the common cabbage (*Brassica oleracea capitata*)f Among these three constituents calcium shows the greatest variation. The mean in each case is the mean of data on the bleached or partially bleached samples (including two of savoy cabbage). For calcium, the mean is 46.0 mg. per 100 gm.; for solids it is 7.6 percent; and for total ash it is 0.72 percent. Frequencies are shown in percentages of these means, using a logarithmic scale. In this way the very high calcium values for unbleached cabbage can be given on the same scale as the low ones for bleached cabbage, and still show the variation in the latter.

increase coincides with a small but significant decrease in the calcium as a percentage of the dry matter.

It is customary in estimating the mineral content of a diet to use a single calcium figure—expressed as a percentage of the fresh material—to represent any particular vegetable, disregarding all such variations as those under consideration here. The fresh green vegetable might be estimated at one figure and the mature seed in the air-dry form at another, but generally no finer distinction is feasible. Thus a single figure for calcium in green vegetable soybeans, say 0.074 percent, would ordinarily be used for any kind that was not fully mature. A general estimate of 0.251 percent of the dry matter is slightly better as an estimate than the average that disregards differences in maturity or in total solids; but even this small improvement in making estimates has no practical value in calculating a given diet unless either the stage of maturity or the moisture or total solids content of the particular sample is known.

In preparing tables it would seem that the calcium content of each variety might be given separately. This would offer a logical solution to the problem, since varietal differences appear to be of most importance; but there are many varieties that might be used, and data are available for only a very few of them. Further experiments may show that the varieties that tend to have more calcium have certain other characteristics in common; and as evidence is accumulated it may be feasible to present data on several classes of soybeans according to type or variety.

Green vegetable soybeans taken as a whole are apparently no more irregular in their calcium content, relatively, than the bleached leaves of cabbage; but since they are a richer source of calcium, the absolute errors introduced into diet estimates by using a single value for all varieties and stages are potentially much greater. Calculations on a day's diet that contained a single helping of 100 grams or 3½ ounces of the vegetable could be in error from this source alone by 35 or 40 milligrams, and this would correspond to an error of about 5 or 6 percent of the daily calcium standard for an adult man.

The two examples, cabbage and soybeans, were chosen not as extreme cases but to show, from material at hand, the variability in foods and its bearing first on the preparation of food-composition tables and finally on dietary calculations.

AVAILABLE IRON

One method for determining the ionizable iron in foods, using the dipyridy reagent, gives results in a number of foods that parallel the biological effect, that is, the hemoglobin response, to some extent (*512*, *1029*). The parallel is not complete, however. The gain in hemoglobin is even slower on some foods than would be expected if the body could make good use of all of the iron determined as ionizable by this chemical method (*1080*). Such lack of correspondence between the quantities that are ionizable and the physiological effect may be due to some other property of the food that hinders the utilization of the iron by the body, or to peculiarities in the biological response of the individual (*456*, *457*). In spite of this lack of agreement, the dipyridyl method may still be suited to measure the kind of iron that the body can utilize when conditions are favorable. In any case, however, further work is needed to develop a more acceptable chemical measure of the quantity of iron that may potentially function as available iron in nutrition.

Nutritionists can now say with some certainty that part of the iron in foods is in effect inert, and that the part that is inorganic and soluble is in a form that, potentially at least, can be utilized by anemic animals. Determinations of ionizable as well as total iron in foods, then, are much to be desired; until further developments, the quantity of ionizable iron in foods, determined by the current modification of the existing method, is the best chemical index we have to the way the food will perform as a source of iron for the body. It has been shown elsewhere in this Yearbook (p. 197) that progress in establishing the iron requirements of human beings can also be advanced when a sharper distinction can be made between iron that is physiologically available and that which is not.

VITAMIN CONTENT OF FOODS

by Esther Peterson Daniel[1]

IN ADDITION to analyzing foods for their content of water, protein, fat, carbohydrate, and minerals, the modern food chemist must determine their vitamin content. Methods for doing this are still difficult and tedious, though the recent discovery of several of the vitamins in pure forms will be a great help. This article gives lists of foods that are exceptionally good sources of vitamins A, C, D, thiamin, riboflavin, and nicotinic acid. The author also tells how the vitamin content of foods is affected by various conditions of production, storage, processing, and cooking, and suggests some practical ways to prevent undue vitamin losses.

SOME twenty-odd years ago the public responded to its introduction to vitamins with a single question: "What good are they?" This question was dramatically and convincingly answered by the production of deficiency diseases in experimental animals receiving diets lacking these important nutrients. Interest immediately centered in discovering vitamin-containing foods which could prevent or cure such deficiency diseases in man, and a long series of tedious experiments was begun in which one food after another was tested on laboratory animals to determine its importance as a vitamin carrier.

Qualitative tables were set up showing what vitamins were present in certain foods, but these soon proved insufficient.[2] It had become evident that vitamins play an important part in health and well-being, and it was seen to be essential not only to learn where to find them but to ascertain in what quantities they are available. And so from the original crude biological tests more carefully controlled methods were gradually devised and units were adopted for measuring the exact vitamin content of a food. Just as it was once arbitrarily decided to let the weight of a grain of wheat be the unit upon which to build the English system of weights, so in the present case it was agreed that a certain defined response in laboratory animals would indicate the presence of 1 unit of vitamin. This is the biological method of measurement.

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[1] Esther Peterson Daniel is Associate Nutrition Chemist, Foods and Nutrition Division, Bureau of Home Economics.

[2] Tables of numerical values for the vitamin content of foods have not been included in this article. In recent years scientists have adopted new units of measure for the well-known vitamins. These units are being used throughout the world to obtain more reliable vitamin values for foods. Too few of our ordinary foods have been measured in terms of the new International Units to justify making a table of numerical values at this time, and it would be unfortunate to perpetuate the older units of measure which are certain to be replaced in the near future.

Meanwhile, the chemical identification of several of the vitamins has aroused interest in finding chemical methods of measurement. The amounts of vitamin A, carotene, and ascorbic acid in foods are now being determined chemically by several investigators, with varying degrees of success.

Knowledge of the vitamin content of foods is essential in analyzing human dietaries and is necessary in providing a practical means of establishing vitamin requirements and in recommending foods that will best meet these requirements.

As the list of vitamin-containing foods grew, it became apparent that each vitamin has its own characteristic distribution. An attempt is made here to point out the more important sources of the different vitamins (*255*, *363*) [3] and to indicate some of the factors that influence and limit the vitamin content of foods.

NATURAL OCCURRENCE OF VITAMINS

VITAMIN A

Vitamin A activity was early associated with highly pigmented foods, particularly those having a deep green or yellow color. This association became extremely puzzling when it was discovered that vitamin A itself is an almost colorless substance that occurs only in a limited number of animal and marine foods. It was some time before scientists recognized that certain yellow-orange pigments, which are contained in many plant and some animal foods, are changed over into vitamin A in the body. These substances, belonging to a class of pigments known as carotinoids, are precursors of the vitamin, and are often referred to as provitamin A. The yellow-orange color of provitamin A may be masked in some foods by the presence of chlorophyll (the green coloring matter in plants), or by other pigments such as lycopene (the red coloring matter in tomatoes). The depth of color of a green or yellow plant food is often a rough indication of the amount of provitamin A that it contains. For example, yellow corn is richer in provitamin A than white corn; sweetpotatoes contain more than potatoes; and green leaves are a better source of this pigment than bleached leaves. On the other hand, there are a few very highly colored foods, such as cranberries and beets, that display little or practically no vitamin A activity.

Although animal foods may contain besides vitamin A some provitamin A which influences their color, depth of color in animal foods is never a dependable index of their vitamin A activity. For instance, although egg yolks generally contain these vitamin A-active pigments in varying amounts, by controlled feeding of the hen it is readily possible to produce highly pigmented egg yolks that contain practically no vitamin A activity. It is equally easy to produce pale-colored yolks that are exceedingly rich in vitamin A.

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[3] Italic numbers in parentheses refer to Literature Cited, p. 1075.

Foods in which vitamin A and provitamin A occur [4] are listed in table 1.

TABLE 1.—*Food sources of vitamin A and provitamin A*

Type of food	Excellent sources	Good sources
Animal products	Fish-liver oils, liver, fish roe, egg yolk, butter, cheese.	Cream, kidney, oysters, whole milk, red salmon.
Vegetables	Kale, spinach, dandelion greens, dock, escarole, chard, lambsquarters, turnip tops, green lettuce, collards, water cress, Chinese cabbage, broccoli, mustard greens, beet greens, carrots, sweetpotatoes, yellow squash, sweet peppers, red tomatoes, green peas, green beans.	Green asparagus, okra, Brussels sprouts, globe artichokes, yellow tomatoes.
Fruits	Apricots, papayas, mangoes, prunes, yellow peaches.	Avocados, guavas, cantaloups, blackberries, black currants, blueberries, bananas, pineapples, green and ripe olives, dates, deep-yellow juice oranges.
Cereal		Yellow corn meal

VITAMIN D

The natural distribution of vitamin D appears to be limited to a comparatively few animal and marine foods; as yet there is insufficient evidence to establish its occurrence in foods of plant origin. Cod-liver oil had been outstanding as an effective cure for rickets even before the recognition of vitamin D, a deficiency of which was found to be the cause of this disease. For many years after the discovery of vitamin D, cod-liver oil was the richest known source of this vitamin. Now it is known that a number of other fish-liver oils, such as those of halibut, tuna, salmon, sardine, and swordfish, outrank cod-liver oil in vitamin D activity, some of them being many times richer in this vitamin than cod-liver oil.

On the other hand, some foods of plant origin contain a substance that is changed into vitamin D upon irradiation with ultraviolet light. Animal foods contain a similar substance which can be activated by irradiation. The ultraviolet rays may be furnished either by the sun or by so-called sun lamps. This method of supplying vitamin D through the irradiation of foods is known as the Steenbock process, from the name of its discoverer. Since one of these provitamin D substances exists in the human body, it is possible to supply an individual with vitamin D by exposure of the body to ultraviolet light.

In addition to foods enriched with vitamin D by the Steenbock irradiation process, the following animal products are natural sources of the vitamin: [4]

Excellent sources: Fish-liver oils and egg yolk (from hens on diet high in vitamin D).

Good sources: Salmon, sardines, eggs, and butter.

Small amounts: Liver, cream, whole milk, and oysters.

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[4] These foods and those listed as sources of the other vitamins have been classified on the basis of equal weights. Consequently their vitamin value in the diet depends not only upon vitamin content but also upon the quantities eaten. A food which contains only a fair amount of vitamins may become a good or an excellent source if liberal quantities are used. Likewise, a food having a very high concentration of vitamin may be included so infrequently or in such small amounts that it offers no real vitamin contribution.

VITAMIN E

Methods for determining the amounts of vitamin E in foods have not been so well worked out as for some of the other vitamins, and less is known about its quantitative distribution. It appears to occur in a great many foods, at least in small quantities. The germ portion of the wheat grain is an especially rich source, while vegetable oils, green leaves, and eggs contain considerable amounts. Scientists at the University of California, who have been interested in vitamin E for a number of years, have published a report in which they discuss its general distribution (*348*).

ASCORBIC ACID (VITAMIN C)

In his efforts to alleviate scurvy among sailors, James Lind, a surgeon in the British Navy, in 1747 found orange and lemon juices effective in curing this condition. By 1795, well over a century before ascorbic acid was discovered, the British Navy was regularly administering lime juice to sailors for the prevention of scurvy. Today citrus fruits are universally recommended, and tomatoes, although containing less ascorbic acid than most citrus fruits, have proved to be a popular and very valuable source of this vitamin.

In some countries it has been said that the potato has been extremely valuable in decreasing the incidence of scurvy. Potatoes are not a particularly rich source of ascorbic acid, but considering the relatively large quantities in which they are generally used, they may contribute important amounts of this vitamin to the diet. Foods containing ascorbic acid [5] are listed in table 2.

TABLE 2.—*Food sources of ascorbic acid (vitamin C)*

Type of food	Excellent sources	Good sources
Animal products	Liver, brain.	Kidney.
Vegetables	Collards, turnip greens, mustard greens, kale, water cress, spinach, dandelion greens, sweet peppers, kohlrabi, rutabagas, turnips, Brussels sprouts, cauliflower, cabbage, broccoli, asparagus, fresh and canned tomatoes, green peas, corn salad, radishes.	Endive, cucumbers, potatoes, sweetpotatoes, green beans, parsnips, rhubarb, leeks, onions, globe artichokes.
Fruits	Guavas, mangoes, oranges, lemons, grapefruit, tangerines, currants, strawberries, gooseberries, raspberries, cantaloups.	Pineapples, cherries, cranberries, papayas, bananas, peaches, apples, avocados, watermelon.
Seeds	Sprouted seeds.	

THIAMIN (VITAMIN B_1)

Our forefathers, in the days before modern machinery made possible the present refining of foods, were unknowingly blessed with a greater abundance of thiamin (sometimes called aneurin) than is generally found in present-day diets. The polishings from rice and the bran and germ portions of grains are among the richest sources of this vitamin. In an effort to meet the human requirement for thiamin, nutritionists are urging the greater use of whole-grain cereals and breads. Meanwhile new milling processes are assisting in providing more thiamin in the diet by replacing in patent flour the germ portions of the grain.

Besides the outstanding plant sources—whole grains, legumes, and nuts—thiamin occurs in many animal and marine foods. A curious observation, which is as yet without explanation, indicates that lean pork is an exceptionally rich source.

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[5] See footnote 4, p. 288.

Since the chemical isolation of thiamin has made possible its use as a standard for vitamin B_1 assay, methods for determining the quantity in foods have greatly improved. In order to extend the meager reliable information regarding the thiamin content of foods, the Bureau of Home Economics tested some 90 foods for thiamin content during 1938–39.

A list of foods containing thiamin in varying amounts [6] is given in table 3.

TABLE 3.—*Food sources of thiamin (vitamin B_1)*

Type of food	Excellent sources	Good sources	Fair sources
Animal products	Lean pork, chicken, kidney, liver.	Egg yolk, brains, lean beef, lean mutton, fish roe, codfish, sardines, whiting.	Fresh milk (whole or skim).
Vegetables	Green peas, green lima beans.	Potatoes, sweet corn, sweetpotatoes, Brussels sprouts, cauliflower, cabbage, mushrooms, spinach, turnip greens, water cress, garden cress, lettuce, collards, kale, onions, leeks, tomatoes, wax and green beans, parsnips, beets, carrots.	Turnips, broccoli, kohlrabi, eggplant.
Fruits		Prunes, avocados, pineapples, oranges, grapefruit, tangerines, dates, figs, plums, pears, apples, cantaloups.	Bananas, watermelons, raspberries, blackberries.
Seeds	Wheat germ, corn germ, rye germ, rice polishings, wheat bran, oats, whole-grain wheat, rye, barley, brown rice, peanuts, soybeans, cowpeas, navy beans, dried peas.	Hazelnuts, chestnuts, brazil nuts, walnuts, almonds, pecans.	

RIBOFLAVIN (VITAMIN G)

Riboflavin, one of the more recently isolated vitamins, has an extremely wide natural distribution. Milk, eggs, meat, green leafy vegetables, whole cereals, and legumes all furnish liberal quantities. Glandular meats such as liver, kidney, and heart are better sources than the muscle meats, and dark meats contain more than light ones.

Food sources of riboflavin [6] are given in table 4.

TABLE 4.—*Food sources of riboflavin (vitamin G)*

Type of food	Excellent sources	Good sources	Fair sources
Animal products	Liver, kidney, heart, lean muscle meats, eggs, cheese, dried (whole or skim), condensed, and evaporated milk.	Fresh (whole or skim) milk, buttermilk, whey.	
Vegetables	Turnip tops, beet tops, kale, mustard greens.	Peas, lima beans, spinach, water cress, collards, endive, broccoli, green lettuce, cabbage, cauliflower, carrots, beets.	
Fruits		Pears, avocados, prunes, mangoes, peaches.	Bananas, cured figs, grapefruit, oranges, apricots, guavas, papayas, muskmelons, apples.
Seeds	Germ portion of wheat, rice polishings, peanuts, soybeans.	Whole-grain wheat, dried legumes.	

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[6] See footnote 4, p. 288.

NICOTINIC ACID (PELLAGRA-PREVENTIVE FACTOR)

Probably no vitamin-deficiency disease is more prevalent in the United States than pellagra, yet the factor or factors effecting its cure are still only partly understood. Only recently has the value of nicotinic acid in the prevention and treatment of this disease been recognized.

The Public Health Service has made a rather extensive study of foods which have pellagra-preventing properties. Over a period of years, certain foods have been found by trial to be more or less effective in preventing or curing pellagra in human beings. Those known to be most effective are lean meats, chicken, liver, green leafy vegetables, legumes, and tomato juice.

A list of good to fair sources of nicotinic acid[7] follows:

Animal products: Liver, salmon, rabbit, fresh and corned beef, lean pork, chicken, buttermilk, egg yolk, skim milk (fresh and dried), evaporated milk, and haddock.

Vegetables: Green peas, collards, turnip greens, kale, tomato juice, cowpeas, soybeans, green cabbage, spinach, and mustard greens.

Seeds: Wheat germ, peanut meal, and green (dried) peas.

OTHER VITAMINS

Vitamin K, the antihemorrhagic factor, is known to occur in large quantities in green leaves. Withering or yellowing of the leaves appears to have no effect on the vitamin. Flowers, roots, and seeds contain much less than green leaves (*253*).

Experiments with laboratory animals have proved the existence of several vitamins other than those discussed, but practically nothing is known concerning their importance in human nutrition.

FACTORS AFFECTING VITAMIN CONTENT OF FOODS

A great many factors affect the vitamin content of foods. Some are environmental influences which can be only partly controlled; others are the result of artificial processes carried out in the attempt to preserve and prepare foods for human consumption. Such factors are universally recognized, but their specific influences on the different vitamins in various classes of foods are still little understood.

The physiological functions of the vitamins, although by no means clearly understood, undoubtedly determine the site of vitamin concentration in plants and animals. In plants ascorbic acid is always present in greatest amounts in the growing parts, and both ascorbic acid and vitamin A are more concentrated in the protective covering, or skin, and in the fleshy portion directly beneath the skin than in the inner flesh.

In animal foods likewise, the vitamins occur in greater concentration in certain body tissues. Liver is the storehouse for many of the vitamins and is thus richer in these nutrients than are muscle meats. Riboflavin occurs in larger quantities in dark meat than in light meat.

VARIETY, SOIL, AND CLIMATE

The variety of plant and the type of soil are factors influencing vitamin content (*1068, 1146*). Over these, man has only partial control.

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[7] See footnote 4, p. 288.

He is frequently restricted to certain varieties of fruits and vegetables best adapted to a given region. The weather conditions and the seasons further influence vitamin formation. An interesting observation made by members of the Bureau of Plant Industry indicates that oranges picked from outside branches well exposed to sunlight contain more ascorbic acid than shaded fruit grown on the same tree.

DEGREE OF MATURITY

The stage of maturity of many plant foods also has an effect on vitamin content (*358*). For example, the vitamin A, thiamin, and ascorbic acid content of tomatoes increases with maturity. In corn, the vitamin A increases until the seed is fully ripened, while ascorbic acid decreases with maturity and ripening. Likewise, as green peas mature the ascorbic acid content diminishes. The Bureau of Plant Industry found that green oranges contain more ascorbic acid than the fully ripened fruit. Spinach, snap beans, and rhubarb show no significant change in ascorbic acid value as they become mature (*1146*).

FEEDING PRACTICES AND BREED

The vitamin value of animal products such as milk and eggs is dependent to a considerable extent upon the diet of the cow and hen (*273, 275, 385, 1056*). At present many poultry and dairy managers recognize the value of feeding vitamin-rich foods for the production of vitamin-rich eggs and milk. Pasture-fed cows give milk that is richer in all the vitamins than stall-fed animals, and plenty of sunshine for the cows assures milk richer in vitamin D.

As the period of lactation progresses, the vitamin A content of milk decreases (*385*), while the quantity of thiamin remains practically constant. Eggs at the beginning of the laying season contain more vitamin A than those produced later by hens receiving the same diet during the entire period (*1056*).

There is also evidence that the breed of cow may slightly influence the vitamin content of milk (*410*).

PRESERVATION AND STORAGE

Very little of our food comes directly from the garden to the table. Much of it is canned, frozen, or dried for later use, when it may be either unavailable fresh or prohibitive in price for the average individual. A large part of the unprocessed food may be delayed for a considerable time in getting to market, held in the market itself, or kept in our own pantries and refrigerators before it is finally prepared and served.

This unavoidable temporary storage of food is always accompanied by certain vitamin losses (*358, 1146*). Type and condition of the food and the length and temperature of storage all influence the degree of loss. Riboflavin, nicotinic acid, and vitamins D and E appear to be little affected during storage; but vitamin A and thiamin are gradually lost, and there may be serious destruction of ascorbic acid.

The effect of storage on ascorbic acid, of all the vitamins, is best understood. As soon as fruits and vegetables are gathered, certain changes take place in their structure that allow a gradual destruction of ascorbic acid. Certain enzymes that are present hasten this destructive action. Thus, delays in marketing or the holding of vegetables like spinach, beans, and peas in household refrigerators or pantries too long before they are used may result in considerably decreased ascorbic acid content. Any bruising, peeling, cutting, chopping, or shredding of the food breaks down the cell walls, frees the enzymes mentioned, and thus accelerates ascorbic acid loss through oxidation (*362*). This explains the recommendation to prepare chopped fruit and vegetable salads immediately before use. The acid in such foods as tomatoes, citrus fruits, and rhubarb helps to preserve ascorbic acid, and extracted juice from these may be stored in the refrigerator for 2 or 3 days and still retain considerable quantities of this vitamin.

Freezing

There is very limited information on the effect of freezing and freezing operations on vitamins other than ascorbic acid (*358*, *360*, *586*). As a matter of fact, freezing itself appears to have no destructive action upon the vitamin content of foods. Losses sometimes attributed to freezing generally occur before the foods are frozen or are a result of improper handling during and after freezing. For example, the manufacturing operations concerned with shelling, washing, and blanching of lima beans and peas have often been found to result in a loss of as much as 50 percent of the ascorbic acid. Slow freezing, slow thawing, or storage of the frozen product above 0° F. (a temperature lower than zero is preferable (*587*)) adversely affects the vitamins. Frozen foods, especially vegetables such as peas, beans, and spinach, rapidly lose ascorbic acid if allowed to stand after thawing, and it is generally recommended that cooking be started while they are still in the frozen condition. Fruits which are to be used uncooked should be served immediately after thawing.

Drying

Foods lose vitamin A, thiamin, and particularly ascorbic acid during drying (*358*), and if the dehydration process is prolonged, these vitamin losses may be serious. Several investigators have found sun drying more destructive than artificial dehydration. Sulfur dioxide, frequently used in commercial practice, tends to prevent the destruction of vitamin A and possibly of ascorbic acid, but does not conserve thiamin. In fact, thiamin is readily destroyed when sulfur dioxide is present.

Very little is known about the effect of drying on the other vitamins. The riboflavin values of dried and evaporated milks would indicate no appreciable destruction of this vitamin. Extremely meager evidence suggests no appreciable loss of vitamins D and E and nicotinic acid in foods due to drying.

Canning

Most vitamin losses in canning are due to oxidation (*358*, *362*, *641*). Consequently the aim in canning methods devised to preserve vitamin content should be to exclude air from the hot food just as much as possible. The so-called open-kettle method of canning with subsequent transfer of the hot food to containers permits greater vitamin destruction than methods in which the foods are processed directly in the jars. Removing the air from the containers before processing further helps to keep down vitamin loss by oxidation. It also minimizes the loss of vitamins during storage of the canned material.

As in cooking, acid foods retain more of their vitamin content during canning than nonacid ones. After canning, citrus fruits and tomatoes, for example, are still excellent sources of ascorbic acid, even though this is the most easily destroyed of the vitamins.

COOKING

Today the art of cooking is more than the production of a tasty dish attractively served; it also includes the conserving of food values (*358*, *362*). While certain vitamin losses during cooking are unavoidable, considerable quantities of these valuable protective substances are needlessly thrown away every day.

Under certain conditions, the oxygen in the air changes vitamins into other substances that do not have the protective properties of vitamins. This process of oxidation is accelerated by heat. Thus, stirring air into foods while they are cooking or sieving them while they are still hot is a frequent cause of vitamin destruction (*577*). An alkaline substance like soda, frequently used to preserve green color in vegetables, also intensifies oxidation, which has a destructive effect on all of the vitamins. Acid, on the other hand, either when added or naturally occurring as in tomatoes and many fruits, helps to protect the vitamins in food during cooking.

In the case of ascorbic acid, oxidation is accelerated by an enzyme referred to as ascorbic acid oxidase (*623*) and also by certain metals such as copper. The enzyme is inactivated by heat; thus, for the conservation of ascorbic acid, it is desirable to employ a method of cooking that rapidly raises the temperature of the food to the boiling point. It was found, for example, that about one-fourth of the ascorbic acid of cabbage was destroyed before boiling and very little after the boiling point was reached, although a considerable quantity was dissolved in the cooking water (*427*).

Ascorbic acid, thiamin, riboflavin, and nicotinic acid all dissolve readily in water; therefore the water in which foods are cooked may acquire considerable amounts of these vitamins. The more water that is used, the greater will be the amount of vitamin dissolved out of the food. It has been pointed out that the cooking water which remains after preparing certain vegetables may be as rich a source of ascorbic acid as tomato juice (*1146*). It is recommended that cooking be done in as little water as possible, and that the water drained from cooked vegetables be served in gravies, sauces, or soups; otherwise, valuable food substances will be lost. The insolubility of vitamins A, D, and E in water prevents loss of these vitamins in this way.

Either steaming or the so-called waterless method of cooking dissolves out less of the water-soluble vitamins than boiling. On the other hand, the more rapid process of boiling helps somewhat to prevent ascorbic acid destruction. These methods of cooking appear to have no significant destructive effect on the vitamins other than ascorbic acid and, to a lesser extent, thiamin. Long cooking processes such as stewing permit greater vitamin losses. Frying is probably the most destructive of the ordinary cooking methods and may result in a complete loss of ascorbic acid, considerable loss of thiamin, and significant destruction of vitamin A. Limited experiments indicate that baking causes somewhat less destruction (*246*, *359*, *362*, *1205*).

Far too little is yet known about the effects of various methods of cooking on the vitamin content of different foods. Ascorbic acid, as the most easily destroyed of the vitamins, has been most intensively studied, but even with it much is still to be learned concerning the effects of various processes.

Most of the foods of man receive some treatment before they reach his dinner table. It is from these cooked, canned, frozen, dried, and stored foods that much of his vitamin requirement must be supplied. In order to establish these requirements and meet them adequately nutritionists realize the great need for extending the present meager knowledge concerning the vitamin losses which occur as a result of these various treatments.

SUGGESTIONS FOR SAVING VITAMINS

So far as the homemaker is concerned, present knowledge might be summed up in the following practical suggestions for the preservation of vitamin values in cooking and serving foods:

Don't stir air into foods while cooking.
Don't put them through a sieve while still hot.
Don't use soda in cooking green vegetables.
In boiling foods, raise the temperature to the boiling point as rapidly as possible.
Use as little water as possible.
Don't use long cooking processes such as stewing when shorter methods are feasible.
Don't throw away the water in which vegetables have been cooked. Use it in making gravies, sauces, and soups.
Don't fry foods valuable for their content of vitamins A, B_1, or C.
Prepare chopped fruit and vegetable salads just before serving.
Start cooking frozen foods while they are still frozen.
Serve raw frozen foods immediately after thawing.

PRESENT-DAY DIETS IN THE UNITED STATES

by Hazel K. Stiebeling and Callie Mae Coons[1]

WHAT are the food habits of the people of the United States? How far do they conform to what is known of good nutrition? What proportion of the families in this country are well nourished, passably nourished, and poorly nourished? Does everyone get as good a diet as he might for his money? In this article, old and new data are examined to answer these and other questions.

IT IS NOW POSSIBLE to say with a fair degree of accuracy what nutritive elements people should have if they are to gain and maintain the best health possible for them as individuals. Thanks to many years of patient research by such men as Sherman at Columbia, McCollum at Johns Hopkins, Mendel at Yale, Atwater of the United States Department of Agriculture, and a host of others in this country and abroad, there is now considerable evidence as to how much of each nutrient a diet should supply and how much can be contributed by each of the many kinds of American food materials.

Hence it is not the insurmountable task that it might appear at first glance to compare meals superficially as different as those of a family whose forebears arrived on the Mayflower and those of a family from the Orient. The family of a laborer making $500 a year might never see many of the foods served regularly at the table of a corporation president with an income of $100,000. Yet in both instances the foods comprising the diets can be classed into the same dozen or so food groups, and the food values can be translated into the same nutritional terms.

It is vital to know the kinds and quantities of food people eat. Careful analyses can then show whether diets have nutritional shortcomings, and recommendations for improvement can be made, taking food preferences and incomes into account. This is important not only for individuals and families, but for communities and even for nations. It takes a surprising amount of work collecting facts and compiling figures to find out what the dietary habits of even a com-

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[1] Hazel K. Stiebeling and Callie Mae Coons are Senior Food Economists, Bureau of Home Economics.

paratively small segment of a population really are, but such work must be done if there are to be any accurate pictures of food needs on which to base efforts at dietary improvement.

This article will deal with food-consumption habits in the United States, considering farm families first, then city and village families, and pointing out various factors that influence the diets of each group. It will draw on scattered data collected over many years, including much unpublished material obtained in a recent study of consumption in relation to income, made by the Bureau of Home Economics in cooperation with other Federal agencies. This study is one of the broadest and most complete, as well as the most recent, made in the United States.

DIETS OF FARM FAMILIES

Most farm families differ from city families in that they not only buy food but produce it for themselves (fig. 1). They count heavily on the garden, the orchard, the poultry flock, the cow, and the meat animals. Food produced on the farm may represent less than half or more than three-fourths of the total money value of the food supply for the family. The amount of food produced varies with the economic status of the family, the size of the farm, the type-of-farming area—including climate and soil—the amount of capital and labor that can be invested in production for home use, and the family's attitude toward home production.

Some people insist that food production for family use is not worth the effort unless the farmer is willing to accept the mere joy of the work as compensation. Others are just as sure that no other acre of land and no equal amount of effort spent in commercial farming have a money-earning value equal to the money-sparing value of farm-furnished food. Few appreciate fully the contributions of farm-furnished food to the family diet—nutritive values worth more than the amount of money involved and not ordinarily purchased even when there is plenty of money. If, as studies indicate, relatively more farm families than city and village families have diets that can be rated as good, this must be attributed to the use of home-produced food. But even with extensive programs of production for home use, expenditure for food still tends to be the largest cash outlay for farm-family living. Usually as much as 20 percent and often more than 30 percent of the cash spent for all family needs goes for food.

How much do farm families actually produce for home use? According to estimates of the Bureau of Agricultural Economics (*1157*),[2] farm families in 1938 produced some $1,250,000,000 worth of food and fuel (valued at farm prices) for home consumption. On the whole, 1938 was a good year for gardens and orchards and for feed crops for poultry, dairy cows, and meat animals. Considerably more food was reserved for home consumption than in 1937, although its money value was lower because of lower prices. But a decline in market values does not diminish the use-value of these goods.

A comparison of the amount and kind of food furnished in 1935–36 by farms in selected type-of-farming areas is shown in table 7 in the

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[2] Italic numbers in parentheses refer to Literature Cited, p. 1075.

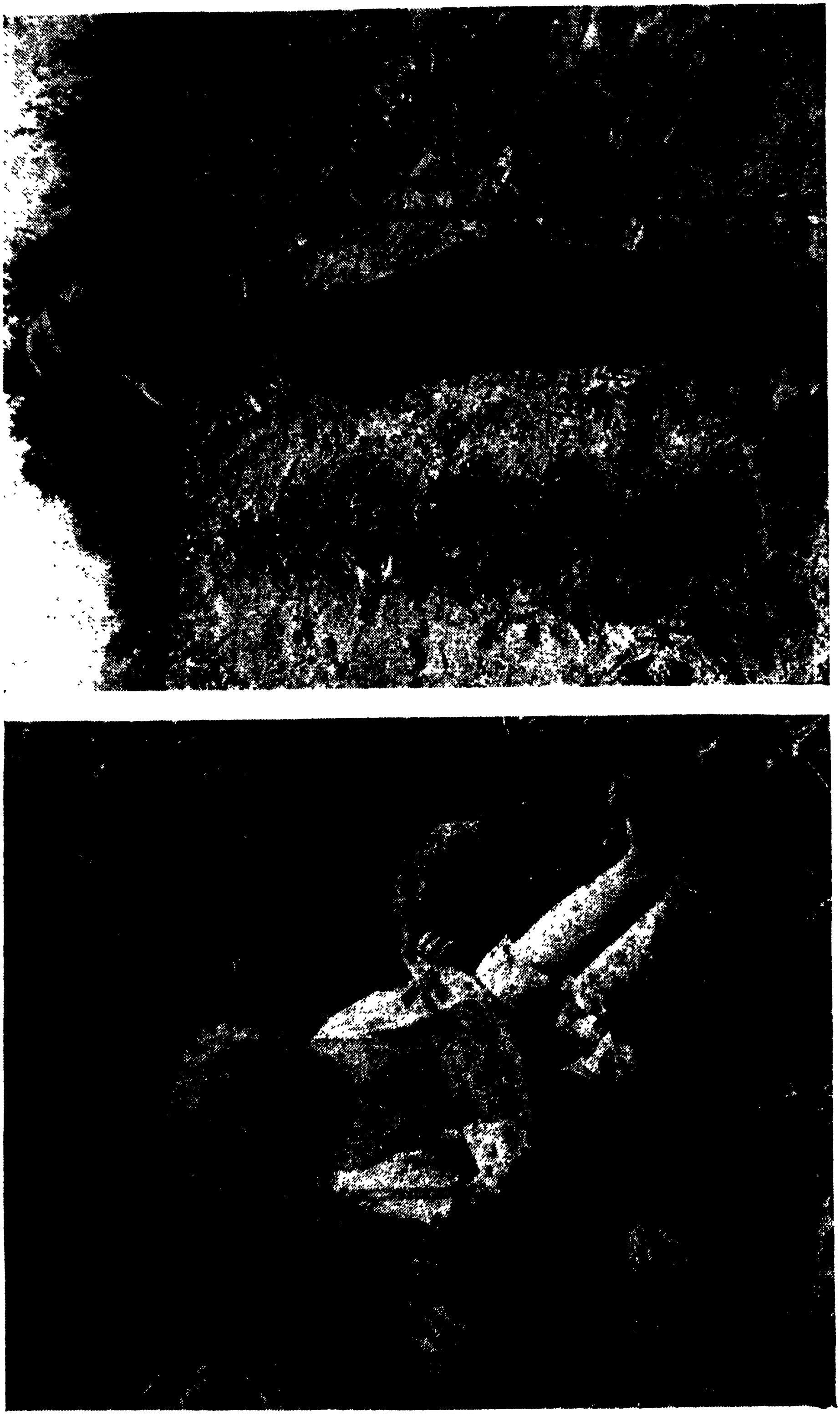

Figure 1.—Why farm families have better diets than city families. They produce part of their own food supply.

appendix (p. 316). These figures [3] refer only to families of nonrelief native-born farm operators. Families on relief, foreign-born, Negroes (except in the Southeast) and other colored races, broken families, families on farms where they had not lived for a year, and sharecroppers and farm laborers were excluded from this study. The reader should keep in mind that the exclusion of these classes of farm families tended to eliminate many of those with the lowest incomes. In addition, the areas chosen as being well adapted to a specific type of farming (as cotton or wheat) often were not typical of the State as a whole but represented better farm land than the average.

Milk appears to be most freely consumed on farms in those counties noted for milk production and in areas where little milk goes to commercial markets and the families tend to consume most of that produced. Many eggs and chickens are used in the Grain Belt, much pork in the Corn Belt, and other meat in the grazing area. A considerable quantity of potatoes are grown for home use in the North, and gardens and orchards are possible in most parts of the country. In some sections, however, notably the Great Plains, climatic conditions interfere with the success of gardens and orchards often enough to discourage plantings. In the Southeast, the amounts of sorghum, field beans and peas, and corn for family use add up to sizable proportions. The fruit and nut section of southern California represents a highly specialized type of agriculture, and families there enjoy comparatively high incomes and more urbanized ways of living than are found in most rural areas of the United States. The effect is seen in the very limited amount of food produced for home use in that section.

In most areas the cash-sparing value of home food production is generally acknowledged. For families consisting of husband, wife, and one child under 16 years of age, living in general farming areas of Pennsylvania and Ohio, and having an average of $630 a year to spend for family living, the general relationship between expenditures for food and the money value of farm-furnished food is shown in figure 2.

The money expenditures for food by these families dropped steadily with increasing volume of home production until a minimum of about $160 a year was reached. This minimum represents the expenditures for articles which could not be furnished by the farm or which, in the families' judgment, it did not pay to produce. Had no food been home-produced, it seems likely from the data at hand that these families would have spent about $265 a year for food.

The difference, about $105, between this estimated maximum expenditure for food and the average minimum does not, of course, represent clear cash gain. Time, energy, and land as well as money must be invested in producing food for family consumption. But when families have only $630 at their disposal for all of their living expenses, they can command many more goods and services that cannot be home-produced if they are able to obtain their food for a direct cash outlay of only $160 rather than $265 a year. The saving represents about 40 percent of the possible food bill and about 17 percent of the total cash spent for living.

The benefits of a suitable program of food production for family use are not confined to cash sparing, however. They also include the health-conserving values of nutritionally adequate diets. The lower a family's money income, the more its well-being depends upon these farm-furnished supplies. Home production tends to improve diets because it helps even families with very low incomes to obtain generous supplies of eggs, milk, butter, and green-colored vegetables—foods so important for their mineral elements and vitamins that they are often called protective foods. The diets of urban families buying all of their food are frequently deficient in these protective foods because they are relatively expensive in city markets. Not only do these foods take much time and effort on the part of farmers to produce, but being perishable, they are costly to transport from farm to market.

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[3] Unpublished data, Bureau of Home Economics, Consumer Purchases Study.

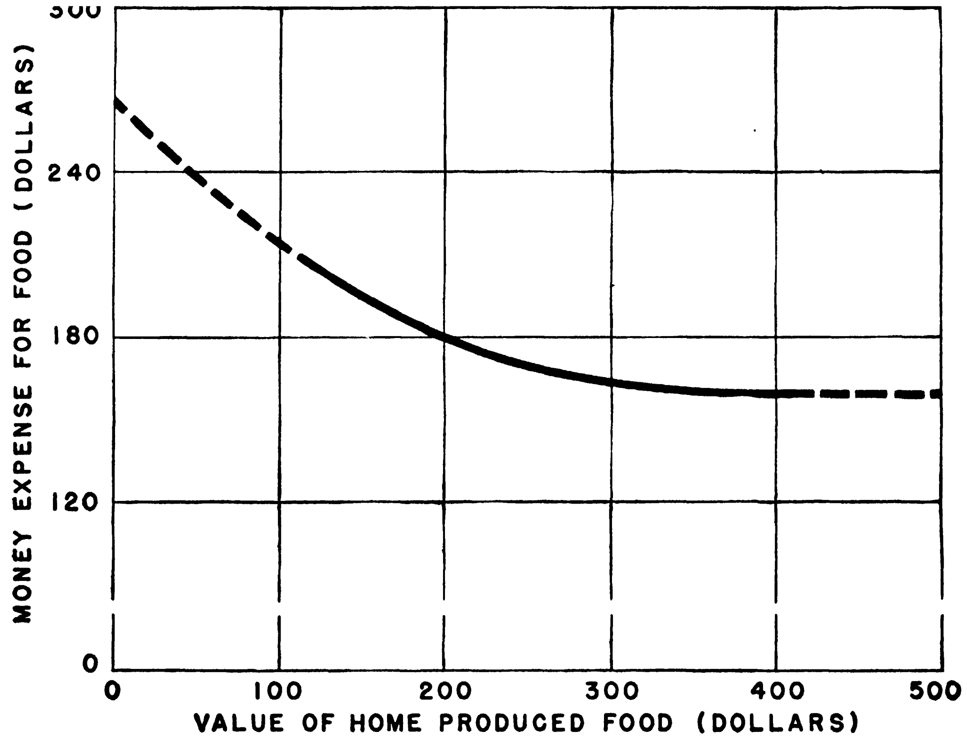

Figure 2.—The more food the farm produces for home use, the less cash the family spends on groceries. Preliminary data based on reports for 1935–36 of 84 nonrelief families of husband and wife (both native-born) with one child under 16 years of age, living in general farming areas of Pennsylvania and Ohio, and having an average of $630 a year for family living expenses.

Since farm families tend to increase the volume of food produced for home use more rapidly than they reduce the amounts spent for food, there is a much better chance that they will get satisfactory diets as programs of food production are enlarged and geared to family needs. Scarcely half of the three-person families just described could have bought even fair diets,[4] nutritionally speaking, if they had spent as little as $265 for food and produced none for family use. On the other hand, probably as many as 7 out of 10 obtained fair or good diets when they produced $150 to $250 worth of food in addition to what they bought. It is likely that about 9 out of 10 of those families that produced as much as $350 worth of food in addition to what they bought obtained fair or good diets.

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[4] See p. 310 for the definition of a fair diet.

The money value of the food consumed usually is greater, and at each income level represents a somewhat larger share of the net income (money and nonmoney), with farm families than with families living in urban or village communities. Farm-family food consumption is large because the heavy outdoor labor of farm workers means high food-energy requirements. As a rule, too, farm families include more members than those of city dwellers.

Diets tend to show more variation from season to season on the farm than in urban centers. Even with extensive canning and storage programs some foods are more plentiful in the country at some periods than at others.

With rising income, quantities of each of the various types of food in the diet tend to become more generous, but the increases are more pronounced for some foods than for others. This is illustrated in table 8 (p. 316), which shows the quantities of food available to families of white nonrelief farm operators during the summer months, for four income classes, in two parts of the country. In the Northeast, families with the higher incomes consumed much larger quantities of cheese, meats, fresh vegetables, and canned fruits. In the Southeast, families with higher incomes consumed larger quantities of eggs, cheese, and meat than those with lower incomes. Farm supplies of these foods tend to be low during the summer months, and only families with higher incomes can purchase them in considerable quantity.

There are also certain regional differences in food supplies. Farm families in the Northeast tend to use more eggs, especially at the lower income levels, than do those in the Southeast. They also consume more cheese, cream, and ice cream, but less fluid milk. Perhaps fewer of the southern families produce milk for sale, and so more is consumed when it is available. Families in the Northeast tend to use less fat but more sugar; less flour and other grain products, but more potatoes; fewer fruits and vegetables in the fresh state, but more in canned form than do farm families in the Southeast.

How adequate are the diets reported by these families of three or four persons? How do they compare with recommendations for good diets?

A good diet may well include an egg a person a day. For three- to four-member families this would mean an average of about 2 dozen a week. Families in the Northeast reported this many eggs or more, but those in the Southeast had somewhat fewer. A quart of milk for each child and a pint for each adult would amount to an average of 17.5 quarts weekly. This amount or more of fluid milk was reported by families in the Southeast. Families in the Northeast had the equivalent of this amount in the form of milk, cheese, cream, and ice cream.

Fully adequate diets for families of this size probably should include also at least 40 pounds of potatoes, other vegetables, and fruit a week. Even in the summer months the diets of families with incomes under $1,000 a year (money and nonmoney) scarcely included this quantity. Since more than 60 percent of the families of nonrelief farm operators in the Southeast and more than 40 percent of those in the Northeast had incomes (money and nonmoney) below $1,000 in 1935–36, according to estimates of the National Resources Committee (*1160*), it would appear that a large proportion of farm-family diets are poorly supplied with fruits and vegetables. In consequence, many farm families consume too little vitamin C to support optimal nutrition.

Of the money spent by farm families for food, the smallest share goes for milk and cheese and the largest for bread, flour, and cereals. But all of the major food groups are represented in cash expenditures. The proportion spent for different groups varies with the extent of the home-production program, but those that produce less have to spend considerably more of their cash for meat and eggs, fruits and vegetables. The following tabulation shows about how each food dollar is spent by families who have to purchase less than one-fourth of their food, and by families who have to purchase more than one-fourth:

	Less than one-fourth purchased	More than one-fourth purchased
Bread, flour, cereals	$0. 33	$0. 27
Sugars	. 18	. 13
Fats	. 15	. 15
Coffee, tea, seasonings	. 13	. 10
Meat, eggs	. 09	. 15
Fruits, vegetables	. 09	. 18
Milk, cheese	. 03	. 02
Total	1. 00	1. 00

Few farm families have enough cash to buy adequate diets without producing some food at home. To get the most out of home production, the farm family would do well to find out by some careful figuring how much of each of the several kinds of foods are required to furnish a fully adequate diet. After such estimates are made, the family can decide how much and what to buy, how much and what to undertake to raise, and what and how much to can and store for out-of-season consumption. The answers will depend on many factors, but careful consideration should be given not only to cash savings but also to maintaining a high dietary level.

The last few years have seen a definite trend toward better planning on the part of the farm family to meet its food needs. The Extension Service has given this program special emphasis since 1930. The Farm Security Administration places the home-production program at the center of the home-and-farm-management plan which is basic to its program of loans and emergency grants. The Farm Credit Administration likewise encourages its borrowers to produce the major part of their food supply.

DIETS OF CITY AND VILLAGE FAMILIES

The food purchases of a city or village family depend largely on two things—the size of the income and the number in the family. At each income level there seems to be a rather striking uniformity in the ideas of families the country over as to what percentage of their incomes should go for food. As table 1 shows, families of wage-earning groups in villages in different parts of the country allotted an average of about 40 percent of their living expenses to food when incomes were under $500 and about 30 percent when incomes were approximately $2,000.[5]

TABLE 1.—*Food expenditures: Average proportion of expenditures for family*[1] *living allocated to food, villages, 1935–36*[2]

Income class (dollars)	New England[3]	North Central[4]	Pacific coast[5]	Southeast[6]
	Percent	*Percent*	*Percent*	*Percent*
250–499	39	42	39	41
500–749	38	40	40	38
750–999	40	40	38	38
1,000–1,249	38	37	35	34
1,250–1,499	35	36	34	33
1,500–1,749	34	34	31	32
1,750–1,999	35	31	31	30
2,000–2,499	33	31	30	28

[1] White nonrelief families of wage earners, including husband and wife, both native-born, and 0 to 8 other persons.
[2] From preliminary unpublished data, Bureau of Home Economics, Consumer Purchases Study.
[3] 14 villages in Vermont and Massachusetts.
[4] 46 villages in Pennsylvania, Ohio, Michigan, Wisconsin, Illinois, and Iowa.
[5] 24 villages in Washington, Oregon, and California.
[6] 33 villages in North Carolina, South Carolina, Georgia, and Mississippi.

At any one income level, the proportion spent for food by large families is higher than that spent by small. Thus city families of two in the $750–$999 income class may use 35 percent of their living expenses for food; families of three or four, 38 percent; and families of five or six, 44 percent.

But though the larger family spends more for food, it seldom spends enough more to maintain the same level per person. For example, table 2, covering small North Central cities in 1935–36, shows that families of two persons with an income of $500 to $749 could afford meals costing about 11 cents a person.[6] When there were four in the family, it took an income of $1,250 to $1,499 to afford approximately 11-cent meals; and with five or six in the family, an income of $2,000 to $2,249.

Though some economies are possible in the purchasing of food for the larger-sized family as well as in the management of food preparation, these seldom compensate for the reduction commonly observed in expenditures per consumption unit. This may be seen from a study of table 9 (p. 317), which compares the quantities of food purchased by families of two persons (husband and wife only) with those of families of three or four persons (husband, wife, and one or two children under 16 years of age) in each of four income classes.

A city or village family with one or two young children bought only one or two more eggs a week than the childless couple with the same income. The family with children bought only about a pint of milk more each day, and usually less than a pound more of meat weekly. But they bought 2 to 3 more pounds of cereals and flour (or its equivalent in bread) each week, and from 2 to 5 pounds more of potatoes. In the case of fresh vegetables the larger families had from 0.1 to 2.5 pounds more per week than the small families, and in the case of fresh fruits, from 0.2 to 5.6 pounds more.

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[5] Unpublished data, Bureau of Home Economics, Consumer Purchases Study.

[6] On a "food-expenditure unit" basis. This unit is equivalent to the expenditure for food for a moderately active man. In comparing the food expenditures of families of different sizes, it is desirable to determine the number of food-expenditure units to which the family is equivalent, i. e., the number of moderately active men that probably could be equally well fed for the same sum as the family group. Expenditures for the food of teen-age children may be 10 percent more than for a moderately active man; for that of other school children and of moderately active women, 10 percent less; and for that of infants and preschool children, from one-half to two-thirds as much. The family's total expenditure for food is then divided by this number of food-expenditure units. The result is the expenditure per food-expenditure unit. When dealing with large groups of families, this corresponds fairly closely with the expenditure per person but it makes possible more accurate comparisons between different families.

TABLE 2.—*Food expenditures: Average amounts spent per food-expenditure unit per meal by families [1] of different size and income, small North Central cities, 1935–36* [2]

Income class (dollars)	Expenditures per meal per food-expenditure unit [3] by families of—			Income class (dollars)	Expenditures per meal per food-expenditure unit [3] by families of—		
	2 persons [4]	4 persons [5]	5 or 6 persons [6]		2 persons [4]	4 persons [5]	5 or 6 persons [6]
	Cents	*Cents*	*Cents*		*Cents*	*Cents*	*Cents*
250–499	8.4	5.9		1,750–1,999	17.8	12.8	10.5
500–749	11.3	7.9	5.0	2,000–2,249	18.6	12.7	10.8
750–999	13.0	8.8	7.0	2,250–2,499	21.0	13.6	10.6
1,000–1,249	15.8	10.3	7.8	2,500–2,999	20.7	15.3	10.9
1,250–1,499	15.7	11.4	9.1	3,000–3,999	22.3	13.5	12.3
1,500–1,749	17.3	11.8	9.8	4,000–4,999	19.8	12.7	15.6

[1] White nonrelief families including husband and wife, both native-born.
[2] From preliminary unpublished data, Bureau of Home Economics, Consumer Purchases Study.
[3] See footnote 6, p. 303.
[4] Husband, wife, and no others.
[5] Husband, wife, and 2 children under 16 years of age.
[6] Husband, wife, 1 child under 16 years, 1 person 16 or over, and 1 or 2 other persons.

Thus the larger families tend to buy proportionally more grain products and potatoes but proportionally smaller quantities of eggs, milk, and fresh vegetables and fruits. As a result, in each income class the diets of the larger families were relatively less well fortified by protective foods and hence less satisfactory from the standpoint of nutrition than were the diets of the smaller families.

Diets of city and village families, like those of farm families, are more generous at higher than at lower income levels, particularly with respect to eggs, milk, meats, fresh vegetables, and fresh and canned fruits. The differences in food consumption of different family groups are more clearly brought out when families are classified by their expenditures for food per unit [7] or per person than when classified by income. The effect of the competition between food and other items for a place in the family budget is eliminated as a variable.

Table 10 (p. 318), based on a recent study of diets of employed city workers (*1104*), shows that families who spend comparatively little for the food of each person buy about as many potatoes, as much of cheaper fats, and as much of flour, cereals, and other grain products for each family member as do those with high food expenditures. But families with more to spend for food buy larger quantities of milk, butter, eggs, meat, fruits, and succulent vegetables, and usually increasingly expensive forms of these foods.

Thus, families in North Atlantic cities spending as little as $1.60 a person a week for food and those spending as much as $4 a person a

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[7] See footnote 6, p. 303.

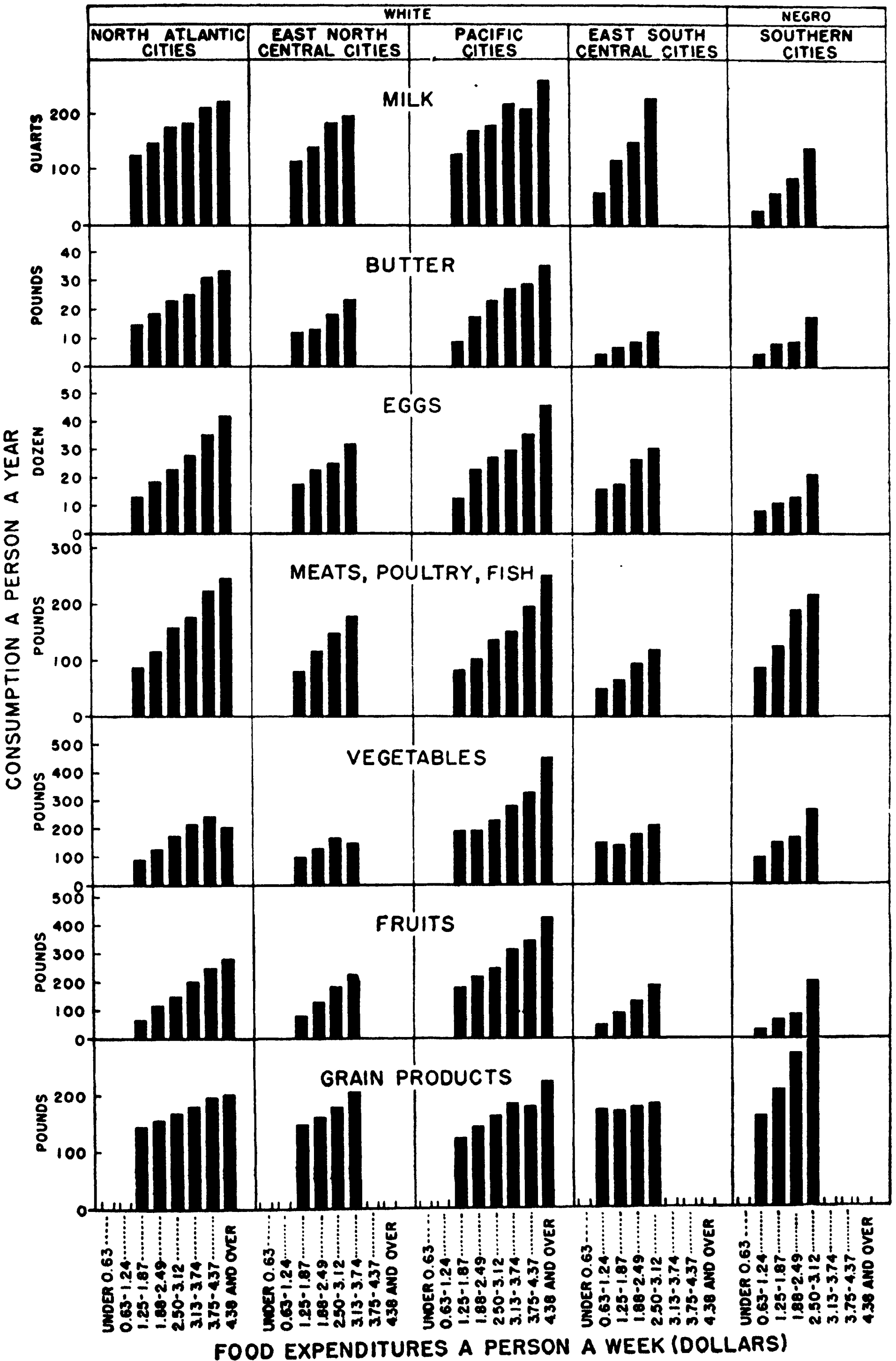

Figure 3.—In the cities, those spending more for food buy more food of practically all kinds. This chart shows the consumption of specified foods by families of employed city workers spending different amounts for food, 1934–37.

week bought approximately the following quantities of certain items for each person:

		$1.60 a week for food	$4 a week for food
Milk, fresh	pints	4	6
Butter	pound	¼	½
Eggs	number	3	8
Meat, poultry, fish	pounds	2	4
Fresh vegetables and fruits	do	3	10

At the higher food-expenditure level the average per capita purchases of citrus fruit were five times as large as those at the lower level. For other fruits and for leafy, green, and yellow vegetables they were about three times as large. Increases were also sharp in purchases of pork, lamb, poultry, and cream. Purchases of potatoes, sugar, and grain products were only one-third to one-half larger at the higher level of food expenditure.

Figure 3 summarizes for different parts of the country what city families of employed workers buy when they have increasing amounts of money for food. Almost without exception, the purchases of all foods increase, but those of some foods, such as eggs, meat, and fruits, go up more rapidly than others. In the South, milk consumption increases unusually rapidly as the level of food expenditure rises.

When city families have about the same amounts to spend for the food of each person there seem to be few regional differences in the purchases of major groups of food. Vegetable and fruit consumption tends to be high in Pacific coast cities and low in the Southeast. Probably characteristic of southern Negro families is the low consumption of milk and butter and the high consumption of pork, poultry, and fish and of grain products.

The average per capita purchases of food by families of employed workers in cities of different regions are given in table 11 (p. 319). But many differences in food consumption commonly considered regional are merely reflections of differences in economic status. The middle half of these families spent the following amounts a person a week for food (figures adjusted to a 1935 base):

White:	
North Atlantic	$2.15--$3.50
East North Central	2.10-- 3.35
East South Central	1.60-- 2.75
Pacific	2.25-- 3.60
Negro: South	1.05-- 2.15

Computations based on table 11 show that workers' families[8] in Pacific cities—half of whom had between $2.25 and $3.60 a person a week for food—used about six eggs a person a week, while the low-income southern Negro families, with $1.05 to $2.15 a person a week for food, had an average of only about two eggs a person a week.

In the purchase of milk also, Pacific families were highest, but even these averaged only about a pint a person a day. White families in the Southeast had an average of only three-fourths of a pint a day, Negro families scarcely a quart a week. These variations also reflect differences in level of food expenditure to some extent. Half of the families studied in Pacific coast cities were spending $2.85 or more a person a week for food. In the Southeast, half of the white families studied were spending less than $2.10 a person a week, and half of the Negro families less than $1.55. Southern white families bought as much milk as white families in other regions when they had comparable amounts to spend for food, though Negro families did not. Low milk consumption seems to be traditional among southern Negro families.

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[8] This study (*1104*) included only nonrelief families with yearly incomes of $500 and over, in which the chief earner had had at least a certain minimum of employment. In Pacific coast cities and among Negro families in southern cities those willing to keep food records are believed to be above average in economic status for this population group and the southern white families, below average.

These figures on milk consumption include not only milk purchased in fluid form, but also that purchased as evaporated or dried milk or as cheese. About one-fourth of the total fluid milk used by southern white families and more than one-half of that used by Negroes was in the form of skim milk and buttermilk.

Marked differences were shown in the consumption of butter and other fats. North Atlantic families purchased the least amount of fats and fatty foods, but they, with Pacific families, were the largest consumers of butter. Negro families used the most fat, largely in the form of lard, bacon, and salt pork—two to four times as much as families in other regions. By region the average quantities consumed by city workers' families per person per year were as follows:

Butter:	*Pounds*	Other fats, oils, and fatty foods:	*Pounds*
Pacific	22	North Atlantic	11
North Atlantic	21	Pacific	17
Southeast, white	8	Southeast, white	41
Southern Negro	7	Southern Negro	58

Less striking were differences in the consumption of meat, poultry, and fish. North Atlantic families purchased an average of 139 pounds a person a year, and southern white families only two-thirds as much—83 pounds a person a year. Consumption of beef and lamb was higher in the North and West than in the South. Southern Negro families used nearly twice as much fish as any other group.

The figures for sugar represent only the quantities purchased as such and do not include the amounts consumed in commercially prepared foods—baked goods, canned fruit, and bottled or other drinks. These figures, therefore, do not compare the actual quantities of sugar consumed in different parts of the country.

In the consumption of cereals, meals, and flour (or its equivalent in baked goods) Negro families in southern cities were highest with an average of 196 pounds a person a year, and Pacific coast families lowest with 160 pounds. In the North and West a large proportion was purchased in the form of bread, rolls, and other ready-to-eat goods made largely from wheat flour. In the Southeast, flour and meal for hot biscuits, corn pone, and other quick breads apparently were preferred to commercially baked bread and other products. White families in this part of the country bought two to three times as much flour and corn meal as those in other regions. Negro families were by far the largest purchasers of hominy and rice.

Potatoes and sweetpotatoes together were used in largest quantities by families of the North Atlantic cities, 157 pounds a person a year, and in smallest quantities by Negro families in southern cities, 91 pounds a year. In the North and West potatoes were used chiefly, but in the southern dietary sweetpotatoes were more prominent. This varying proportion affects the vitamin content of the diet. Potatoes contribute outstandingly to the vitamin C and sweetpotatoes to the vitamin A value.

Tomatoes and citrus fruit, important for vitamin C, were used most freely in the Pacific coast cities, and least by Negro families in the Southeast. Families in Pacific cities consumed two to three times as much citrus fruit as white families in other regions.

The purchases of succulent vegetables (vegetables other than potatoes and mature beans and peas) were almost twice as great among Pacific families as among southern Negro families. Leafy, green, and yellow vegetables are important among these foods because of their high mineral and vitamin content. Families in Pacific cities consumed by far the largest quantities of the green, leafy, and yellow vegetables of any group studied and those in East North Central cities the least. The average consumption by the two groups was 122 and 60 pounds a person a year, respectively. The average for Negro families in the South was about 91 pounds a person a year.

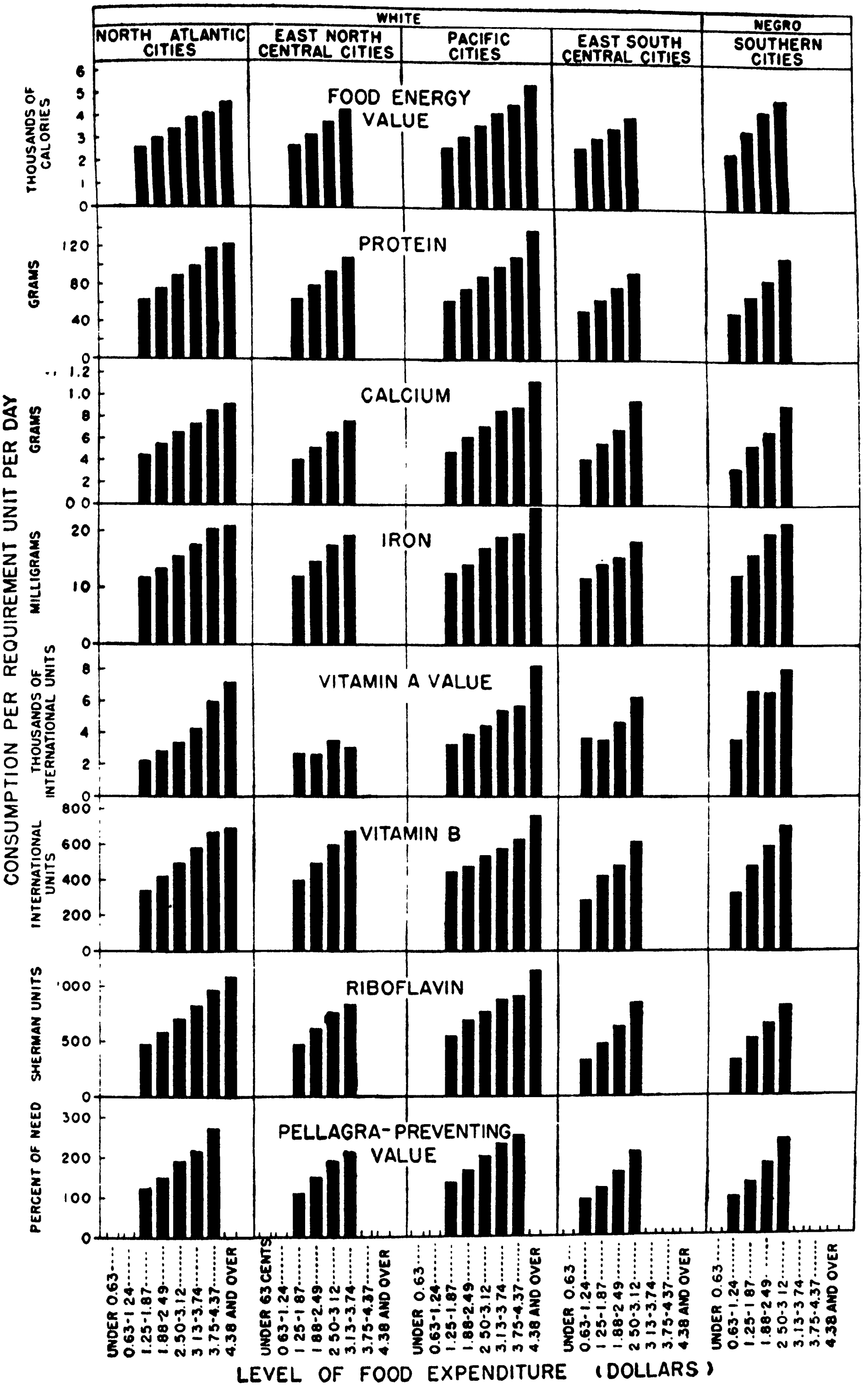
In consumption of fresh and canned fruit, as in the case of fresh and canned succulent vegetables, the Pacific coast families ranked first, and southern Negro families at the foot of the list. Of the fruits, apples, oranges, and bananas were most largely used. The Pacific city families bought more peaches and grapes than did families in other regions. Southern families, particularly Negroes, depended largely upon their local supplies of fruit, especially on watermelons. In fact, the Negro families studied in the South had meager quantities, 5 pounds or less a person a year, of any one fresh fruit except watermelons.

NUTRITIVE VALUE AND ADEQUACY OF DIETS

An estimate of the nutritive value of diets can be made by applying average figures on food composition to the quantities of food consumed. The reader should keep in mind, however, that the figures on the nutritive value of many foods are tentative and subject to revision, especially in the case of minerals and vitamins. Recent work (1939) suggests that the estimates given in this article for vitamin A value of diets may be too low. The figures were based on data available prior to 1937.

Figure 4 gives a graphic picture of the nutritive value of diets at different levels of expenditure in different regions. It shows nutritive values of food purchased by families of employed city workers (*1104*) representing five color-regional groups and several different levels of expenditure. These average figures on nutritive content tend to be high, however, inasmuch as they refer to food brought into the kitchen and take no account of the edible food waste, which probably increases with prosperity, or of the losses of nutrients in food preparation. Only average quantities of inedible refuse were deducted.

Figure 4.—In general, the higher the level of food expenditure, the better the diet. This chart shows the nutritive value per nutrition-requirement unit—equivalent to the allowance for a moderately active man weighing 154 pounds per day—of diets of families of employed city workers spending different amounts for food, 1934–37.


WHITE
NEGRO
NORTH ATLANTIC CITIES
EAST NORTH CENTRAL CITIES
PACIFIC CITIES
EAST SOUTH CENTRAL CITIES
SOUTHERN CITIES
CONSUMPTION PER REQUIREMENT UNIT PER DAY
FOOD ENERGY VALUE
THOUSANDS OF CALORIES
0
1
2
3
4
5
6
PROTEIN
GRAMS
0
40
80
120
CALCIUM
GRAMS
0 0
2
4
6
8
1.0
1.2
IRON
MILLIGRAMS
0
10
20
VITAMIN A VALUE
THOUSANDS OF INTERNATIONAL UNITS
0
2
4
6
8
VITAMIN B
INTERNATIONAL UNITS
0
200
400
600
800
RIBOFLAVIN
SHERMAN UNITS
0
500
1000
PELLAGRA-PREVENTING VALUE
PERCENT OF NEED
0
100
200
300
UNDER 0.63
0.63-1.24
1.25-1.87
1.88-2.49
2.50-3.12
3.13-3.74
3.75-4.37
4.38 AND OVER
UNDER 63 CENTS
0.63-1.24
1.25-1.87
1.88-2.49
2.50-3.12
3.13-3.74
3.75-4.37
4.38 AND OVER
UNDER 0.63
0.63-1.24
1.25-1.87
1.88-2.49
2.50-3.12
3.13-3.74
3.75-4.37
4.38 AND OVER
UNDER 0.63
0.63-1.24
1.25-1.87
1.88-2.49
2.50-3.12
3.13-3.74
3.75-4.37
4.38 AND OVER
UNDER 0.63
0.63-1.24
1.25-1.87
1.88-2.49
2.50-3.12
3.13-3.74
3.75-4.37
4.38 AND OVER
LEVEL OF FOOD EXPENDITURE (DOLLARS)

When food expenditures were as low as $1.25 to $1.87 a person a week, diets were rather restricted. With more money to spend for food, the nutritive content of diets increased.

Families in North Atlantic cities may be taken as an example. The following comparison shows the nutritive values per nutrition-requirement unit for diets costing $1.25 to $1.87 a person a week and for those costing $2.50 to $3.12:

	$1.25-$1.87 a week	$2.50-$3.12 a week
Energy value calories	2, 530	3, 320
Protein grams	64	88
Calcium do	0. 44	0. 65
Phosphorus do	1. 07	1. 46
Iron milligrams	11. 30	15. 40
Vitamin A value International Units	2, 100	3, 400
Vitamin B_1 do	340	500
Ascorbic acid (vitamin C) milligrams	41	70
Riboflavin (vitamin G) Sherman units	470	700
Pellagra-preventive value percent of minimum	120	190

Individual families, however, varied widely from the prevailing patterns of nutritive values in relation to expenditure. For example, some families selected diets furnishing only 45 grams of protein per nutrition-requirement unit a day at an outlay of $1.88 a person a week for food; on the other hand, for this sum half of the families obtained diets furnishing 70 grams or more per nutrition-requirement unit a day. Or, to take a more striking illustration, some families spent as much as $4.50 for food a person a week without obtaining 0.45 gram of calcium a day per requirement unit. On the other hand, half of the families spending $3 a person a week succeeded in getting 0.70 gram or more of calcium per requirement unit daily.

Diets may be classified as good, fair, or poor according to their nutritive content. In recent studies made by the Bureau of Home Economics, they have been designated good or fair if the food materials (uncooked) furnished per nutrition-requirement unit at least the quantities of nutrients shown in table 3. Diets were classed as poor, in need of improvement, if per nutrition-requirement unit the raw foods provided less of any one nutrient than the quantity shown for a fair diet.

TABLE 3.—*Specifications for diets rated good and fair; daily allowances of certain important nutrients per day for a 154-pound moderately active man*

Nutrient	Good diets	Fair diets	Nutrient	Good diets	Fair diets
Protein grams	67	45	Vitamin A International Units	6, 000	3, 000
Calcium do	0. 68	0. 45	Vitamin B_1 do	500	250
Phosphorus do	1. 32	. 88	Ascorbic acid milligrams	75	37
Iron milligrams	15	10	Riboflavin Sherman units	600	300

Table 12 (p. 320), gives the specifications for a good diet in greater detail—that is, for persons of both sexes and various ages.

Poor diets are seldom deficient in only one nutrient. But in this study of the diets of families of city wage earners, relative shortages of some nutrients were encountered more frequently than others.

Less than 2 percent of the employed white workers studied are believed to have diets furnishing less than 45 grams of protein per requirement unit daily—the average minimum below which the diet is classed as poor. About 5 percent had diets furnishing less than 10 milligrams of iron per unit per day; about 16 percent, less than 0.45 gram of calcium; and about 40 percent, fewer than 3,000 International Units of vitamin A.[9]

In the studies just cited, diets of families of employed workers in cities were practically always found to be in definite need of improvement with respect to one or more nutrients when families spent for food less than $1.25 (1936 price levels) a food-expenditure unit a week. Farm diets[10] were poor when families had food valued at less than $0.80 a unit a week. (The monetary value of farm diets is lower because home-produced food was valued at prices that were less than those found in city retail stores.) Five percent of the nonrelief city, village, and farm families were found to have food valued at less than these amounts. This does not mean, however, that only 5 percent had poor diets. Even some of the relatively well-to-do families spent far too little for food to buy adequate diets.

For village and city families[10] the chances for better diets increased with rising per capita expenditures for food. This was due chiefly to the purchase of more liberal quantities of milk, meat, eggs, leafy green vegetables, and fruits. About 10 percent of the diets classed as good were actually purchased by city and village families for less than $2.50 a person a week. This amount may perhaps be taken as a reasonable yardstick of the minimum cost of a good diet. Although 65 percent of city and village families were spending $2.50 or more, far too few bought diets that could be rated as good from the standpoint of nutrition. A fairly large proportion bought diets rated fair. The others, a too large number, bought diets that had to be classed as poor. It is clear, therefore, that expenditures for food are not the only factor influencing nutritive adequacy of diets. Knowledge of food values is also essential.

A larger proportion of farm families than city families were found to have fair or good diets, thanks to the farm-furnished protective foods. In every region families living on farms tend to rank first in the proportion having good diets. Those in metropolises, large cities, and middle-sized cities rank second. Village families fare worst of all. This parallels the finding of Dorn (*279*) that the number of cases of illness per 1,000 person-years of exposure was greatest in village communities and smallest in the open country.

The chief difference between good diets and average diets is in the quantities of protective foods. For the country as a whole, it is esti-

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[9] An idea of the general level of nutritive content of diets can be obtained by leaving out the poorest one-fourth and the best one-fourth. The middle 50 percent of the diets of white families included in this study provided the following quantities of nutrients per requirement-unit per day:

Protein	grams	70–95
Calcium	do	0.50–0.83
Iron	milligrams	14–17
Vitamin A value	International Units	2,000–4,500
Vitamin B_1	do	400–600
Ascorbic acid (vitamin C)	milligrams	50–100
Riboflavin (vitamin G)	Sherman units	550–900

These diets appear to have been least well fortified in vitamin A value and in calcium, and best fortified in protein.

[10] Unpublished data, Bureau of Home Economics.

mated that freely chosen diets rated as good probably include 20 percent more milk than do customary diets. They also include 15 percent more butter, 35 percent more eggs, 70 percent more tomatoes and citrus fruit, and about 100 percent more leafy green and yellow vegetables.

The quantities of certain protective foods found in the city, village, and farm diets rated as good are given in table 4, together with quantities included in plans for good diets devised by the Bureau of Home Economics. Each family diet from which these average quantities were derived met the specifications for a good diet described earlier. The low quantities of milk, tomatoes, and citrus fruits appearing in the diets of southern Negro families are balanced to give good diets by the large quantities of leafy, green, and yellow vegetables consumed.

TABLE 4.—*Content of good diets: Average quantities of specified foods per person per year found in diets classed as good, compared with plans for good diets*

Item	Eggs	Milk or its equivalent[1]	Butter	Tomatoes, citrus fruits	Leafy, green, and yellow[2] vegetables	Other vegetables and fruits[3]
Family diets graded good:						
Nonrelief families:[4]	*Dozen*	*Quarts*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Farms	28	330	23	90	180	285
Villages	25	130	18	65	200	295
Small cities	35	240	23	175	150	315
Middle-sized cities	27	200	26	110	150	305
Large cities	32	200	20	140	150	310
Families of employed city workers:[5]						
White families:						
North Atlantic	23	187	18	115	128	174
Pacific	24	228	18	296	217	473
East South Central	32	273	15	131	166	177
Negro families, South	18	114	14	31	263	208
Plans for good diets[6]	17-30	230-260	20-40	65-120	160-180	130-350

[1] The following are approximately equivalent to the food value of 1 quart of fluid whole milk: (1) 17 ounces of evaporated milk; (2) 1 quart of fluid skim milk and 1½ ounces of butter; (3) 5 ounces of American Cheddar cheese; (4) 4½ ounces of dried whole milk; (5) 3½ ounces of dried skim milk and 1½ ounces of butter.

[2] Does not include sweetpotatoes.

[3] Does not include potatoes, sweetpotatoes, mature dry legumes. Includes fresh fruit equivalent of dried fruits.

[4] Preliminary unpublished data, Bureau of Home Economics, Consumer Purchases Study.

[5] Families of employed wage earners spending less than $3.13 a person a week for food (*1104*).

[6] Based on quantities suggested by Bureau of Home Economics for good diets at 3 food-expenditure levels, described in detail in the article, Planning for Good Nutrition, p. 321.

FIFTY-YEAR TRENDS IN FOOD CONSUMPTION

Differences in food habits by regions, especially among urban groups, probably are less apparent now than formerly. Modern city markets offer throughout the year a great variety of foods from which the housewife may choose. Fresh fruits, vegetables, and other perishable foods are rapidly transported in good condition, perhaps thousands of miles from the site of production, or are kept under special storage conditions for weeks beyond the production period. Much variety has been made possible also by commercial canning. In addition, there is a growing assortment of foods preserved by quick freezing, which retain many of the characteristics of fresh products. The effect of these improved facilities and methods for storing, shipping, marketing, and preserving food products has been to eliminate the influence of time and place upon the availability of many foods and to extend the season for others. As a result, the modern city family can choose from a variety and abundance unheard of 50 years ago.

Trends in the consumption of important groups of food may be seen from the summary given in table 5 of dietary studies made decade by decade among village and city families.

TABLE 5.—*City and village family food: Trends in average per capita consumption per year of specified foods by level of food expenditure, 1885–1937* [1]

Level of food expenditure [2] and period	Grain products	Meats, fish, poultry	Milk [3] or its equivalent	Eggs	Leafy, green, and yellow vegetables [4]	Tomatoes, citrus fruits
$1.25–$1.87 a person a week:	*Pounds*	*Pounds*	*Quarts*	*Dozen*	*Pounds*	*Pounds*
1885–1904	294	123	41	12	24	10
1905–14	240	124	90	12	31	15
1915–24	174	84	101	15	35	38
1925–34	152	85	112	12	43	37
1935–37	155	85	118	16	53	45
$1.88–$2.49 a person a week:						
1885–1904	222	169	90	24	29	22
1905–14	239	157	90	14	39	46
1915–24	178	87	186	18	62	57
1925–34	172	104	135	15	70	39
1935–37	160	106	150	23	76	75
$2.50–$3.12 a person a week:						
1885–1914	218	204	84	20	48	59
1915–24	204	115	180	26	67	73
1925–34	163	129	144	24	83	68
1935–37	174	139	191	27	95	98

[1] Based on averages from many scattered family dietary studies, published and unpublished, compiled by the Bureau of Home Economics.

[2] Adjusted to 1935 levels by use of U. S. Bureau of Labor Statistics index of retail food costs.

[3] See table 5, footnote 1.

[4] Does not include sweetpotatoes.

Over the 50-year period a sharp decline took place in the consumption of grain products and meats among families at a comparatively low level of food expenditure ($1.25 to $1.87 a person a week, at 1935 retail food-price levels). This decline was also evident for families with average and higher-than-average expenditures, but to a lesser degree. Per capita purchases of grain products before 1915–24 were higher among families with little money for food than among their more affluent neighbors. Today, this is apparently reversed. Among families spending less-than-average amounts for food, meat consumption fell to a low level in 1915–24, and since that period has increased very little. On the other hand, among families spending more-than-average amounts, meat consumption declined relatively less in the decade 1915–24, and since then has increased somewhat.

In general there has been a marked upward trend at each food-expenditure level in the consumption of milk, the green leafy vegetables, and tomatoes and citrus fruits. These are the so-called protective foods that abound in the nutrients often deficient in low-cost diets.

The trends recorded by these dietary studies are corroborated in general by estimates of the per capita disappearance of food in retai markets. One such estimate,[11] covering approximately the last two decades, is given in table 6. It shows how the emphasis in consumption has shifted from one food group to another, even though the total weight of food consumed a person a year has remained fairly constant. These figures indicate a downward trend for meats, grain products, and potatoes, and an upward trend for the protective foods—milk and cream, succulent vegetables, and fruits.

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[11] Unpublished data, Agricultural Adjustment Administration.

Table 6.—*Food sold in retail market: Estimated yearly per capita disappearance of specified foods or groups of foods, by periods, 1920–37* [1]

Item	1920–24	1925–29	1930–33	1934–37
	Pounds	*Pounds*	*Pounds*	*Pounds*
Cereal products [2]	229	226	211	196
Potatoes, sweetpotatoes	178	164	156	157
Sugar and sirup	106	118	107	110
Dairy products:				
Milk and cream [3]	315	334	337	328
Butter	17	17	18	17
Other manufactured	23	28	28	32
Fruits:				
Fresh [4]	179	192	184	189
Dried	6	6	5	6
Vegetables [5]	135	148	154	169
Lean meats and fish	138	133	129	126
Eggs	28	32	32	30
Beans, peas, nuts	11	14	16	16
Fats other than butter [6]	44	47	47	45

[1] Data from Program Planning Division, Agricultural Adjustment Administration, Dec. 15, 1938.

[2] Wheat, rye, buckwheat flour, corn meal and corn flour, rice, and cereal breakfast foods; grain for liquors, malt, and cornstarch excluded.

[3] Whole milk and cream in terms of whole milk.

[4] Fresh and canned fruit in terms of fresh fruit, on basis of total population; consumption of watermelons and cantaloups per urban inhabitant.

[5] Fresh and canned vegetables in terms of fresh, per urban inhabitant.

[6] Lard and lard compounds, vegetable oils, margarine, bacon, and salt pork.

Figure 5, based on year-by-year estimates (*1159*) covering a longer period than table 6, 1910–31, shows similar trends for certain foods. There has been a phenomenal rise in the consumption of citrus fruits, a marked upward trend in the consumption of succulent vegetables, and a moderate but steady increase in milk consumption. Among foods high in energy value, sugar has risen rapidly, while grain products and potatoes show a marked decline.

ROOM FOR IMPROVEMENT IN DIETS

If the total quantities of food produced in this country were distributed in proportion to need, a fairly satisfactory diet would be provided for every individual. As it is, the national dietary level appears high because of the high consumption of certain foods by some families. Urban families with limited funds for food and rural families with restricted opportunities for home production tend to lay emphasis on the kinds of food that satisfy obvious hunger cheaply and to neglect those that satisfy also the "hidden nutritional hungers"—for vitamins and minerals—described by science.

Many diets in this country are in need of improvement. For some families this reflects a lack of appreciation of the relation of diet to buoyant health, physical efficiency, and long life. For others it indicates that the family's knowledge of food values in relation to food prices is inadequate for practical application to the planning of everyday meals. For still others it implies insufficient purchasing power.

Modification of present-day diets so as to improve their nutritive qualities without adding much to their cost is chiefly a matter of putting considerably more emphasis upon milk in its less expensive forms and upon the cheaper leafy and green-colored vegetables. Many

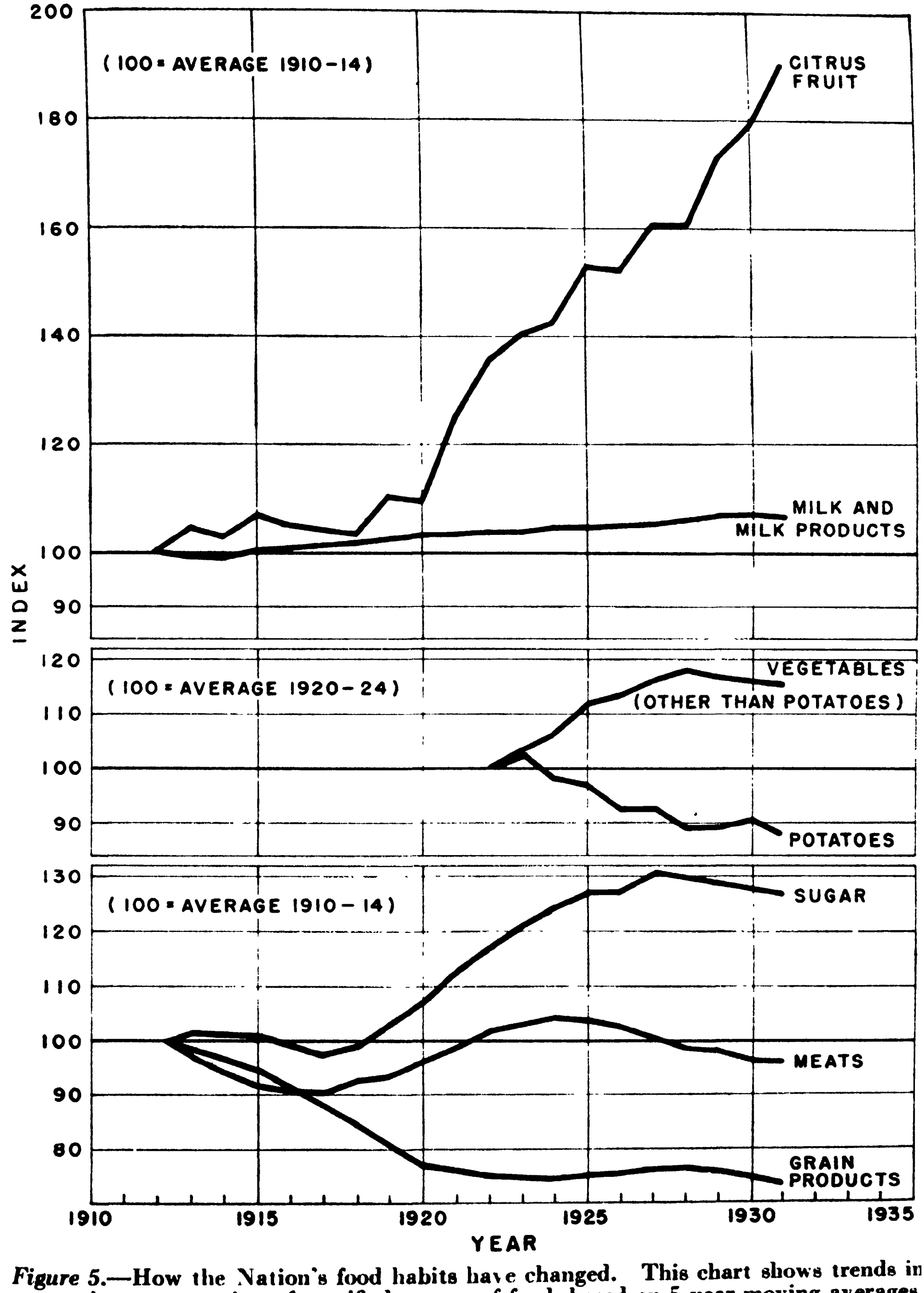

Figure 5.—How the Nation's food habits have changed. This chart shows trends in per capita consumption of specified groups of food, based on 5-year moving averages.

varieties and forms of these foods yield excellent returns in nutrition for their cost.

APPENDIX

TABLE 7.—*Farm-furnished food for home use: The average supply for a household*[1] *for a year in areas representing different types of farming, 1935–36*[2]

Selected counties in—	Type of farming represented	Families included	Average quantities or money value of food produced for home consumption								
			Milk	Eggs	Poultry	Pork	Other meat	Potatoes	Other food from garden	Fruits	Other food[3]
		No.	*Gal.*	*Doz.*	*No.*	*Lb.*	*Lb.*	*Bu.*	*Dol.*	*Dol.*	*Dol.*
Vermont	Dairy	513	326	124	17	139	112	42	43	4	7
Ohio	General	814	212	146	36	440	155	23	38	15	5
Illinois	Corn or cash grain	838	248	160	68	637	148	12	22	4	(4)
Kansas	Wheat or cash grain	557	264	176	97	328	159	2	10	(4)	(4)
Colorado, Montana, South Dakota.	Range livestock and cash grain.	794	281	178	55	290	296	19	43	7	3
Oregon	General and fruit	1,611	251	138	35	195	119	14	45	23	1
Southern California	Fruit and nut	1,080	93	74	20	8	11	1	6	11	(4)
South Carolina:											
White	Cotton and tobacco	2,048	287	113	64	659	12	7	51	8	23
Negro	do	478	158	59	36	363	5	4	32	4	30

[1] Nonrelief families of farm operators, including husband and wife, both native-born, 0 to 8 other family members, and household and farm help.
[2] From unpublished data, Bureau of Home Economics, Consumer Purchases Study.
[3] Includes sirup, molasses, honey, grain products, and cowpeas and other foods grown in fields.
[4] $0.50 or less.

TABLE 8.—*Farm-family*[1] *food: The average supply for a household for a week, by region and income class, summer 1936*[2]

Region and income[3] class (dollars)	Eggs	Fluid milk	Evaporated condensed milk	Cheese	Cream, ice cream	Fats	Meats,[4] poultry, fish	Flours,[5] cereals
Northeast:	*Doz.*	*Qt.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*
500–999	2.2	15.6	0.1	0.5	2.3	3.3	8.0	11.4
1,000–1,499	2.6	16.6	0	.6	2.5	3.9	10.9	12.9
1,500–1,999	2.8	16.5	.1	1.0	2.8	3.6	11.7	14.0
2,000–2,999	2.7	17.3	.1	1.0	2.5	4.0	14.1	14.8
Southeast:								
500–999	1.4	20.8	(6)	.1	.6	5.2	9.4	24.4
1,000–1,499	1.7	19.7	.1	.4	.6	5.5	12.3	27.0
1,500–1,999	2.1	23.9	.1	.4	.9	6.0	14.6	24.0
2,000–2,999	2.9	23.6	.1	.8	.5	5.8	14.3	25.7

Region and income[3] class (dollars)	Sugar	Other sweets	Potatoes, sweetpotatoes	Other vegetables			Fruits		
				Fresh	Canned	Dried	Fresh	Canned	Dried
Northeast:	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*
500–999	5.6	1.8	17.1	6.7	3.3	0.3	7.5	1.5	0.5
1,000–1,499	6.6	2.2	20.6	7.9	3.0	.6	9.1	1.8	.4
1,500–1,999	6.8	2.6	22.5	10.0	3.1	.3	11.8	2.3	.6
2,000–2,999	7.6	3.0	23.8	14.0	3.1	.9	11.0	2.9	.4
Southeast:									
500–999	4.8	1.9	4.7	16.1	.3	.2	15.0	.3	.1
1,000–1,499	5.1	3.0	6.0	15.2	.9	.2	17.2	.6	.2
1,500–1,999	5.5	2.1	4.7	19.1	.9	.6	8.9	1.4	.3
2,000–2,999	5.8	1.7	8.8	20.7	1.0	.2	11.2	.3	.1

[1] White nonrelief families of farm operators, including husband and wife, both native-born, and 1 or 2 children under 16 years of age.
[2] From preliminary unpublished data, Bureau of Home Economics, Consumer Purchases Study.
[3] Money and nonmoney.
[4] Includes bacon and salt pork.
[5] Two-thirds of the weight of bread and other baked goods has been added to the weight of the flour, meals, and other cereals.
[6] 0.05 pound or less.

TABLE 9.—*City- and village-family food: Average supply for a week for two types of families,*[1] *by income, small East North Central cities, spring-summer-fall, 1936* [2]

Degree of urbanization, type of family, and income (dollars)	Eggs	Milk or its equivalent [3]	Fats	Meats,[4] poultry, fish	Flour,[5] meals, cereal	Sugar	Other sweets
Small cities:							
Families of husband and wife with incomes of—	*Dozen*	*Quarts*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
500–999	1.2	5.7	2.5	5.2	6.2	3.0	0.6
1,000–1,499	1.5	8.5	2.5	7.4	7.2	3.8	.7
1,500–1,999	1.4	7.2	2.0	6.2	5.8	3.6	.8
2,000–2,999	1.8	9.5	2.7	9.2	6.1	4.0	.9
Families of husband, wife, and 1 or 2 children under 16 years, with incomes of—							
500–999	1.4	9.3	2.6	5.9	8.0	4.0	.8
1,000–1,499	1.6	11.7	2.6	7.3	8.1	4.3	1.0
1,500–1,999	1.6	11.7	3.1	7.9	8.6	4.5	1.2
2,000–2,999	1.7	11.6	3.2	10.1	7.8	4.3	1.0
Villages:							
Families of husband and wife with incomes of—							
500–999	1.3	7.5	2.2	5.6	6.8	3.1	.8
1,000–1,499	1.6	8.6	2.4	7.4	6.7	2.9	1.2
1,500–1,999	1.6	9.7	2.6	7.6	7.1	3.2	1.4
2,000–2,999	1.6	9.8	2.7	8.7	7.8	3.9	1.0
Families of husband, wife, and 1 or 2 children under 16 years, with incomes of—							
500–999	1.5	10.2	2.9	6.4	10.0	3.8	1.5
1,000–1,499	1.7	12.3	3.0	8.0	10.0	4.0	1.4
1,500–1,999	1.7	13.4	3.0	9.6	9.9	3.8	1.4
2,000–2,999	1.9	15.8	3.1	9.9	11.0	4.2	1.7

Degree of urbanization, type of family, and income (dollars)	Potatoes, sweetpotatoes	Other vegetables			Fruits		
		Fresh	Canned	Dried	Fresh	Canned	Dried
Small cities:							
Families of husband and wife with incomes of—	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
500–999	7.2	2.7	2.4	0.9	5.1	0.7	0.4
1,000–1,499	9.0	5.0	2.2	.5	8.7	.8	.3
1,500–1,999	7.3	4.1	2.6	.4	10.2	1.1	.3
2,000–2,999	7.5	5.9	1.6	.4	10.8	.8	.3
Families of husband, wife, and 1 or 2 children under 16 years, with incomes of—							
500–999	10.5	4.2	2.9	.7	8.5	.6	.4
1,000–1,499	10.9	5.1	3.1	.5	10.3	.9	.4
1,500–1,999	10.8	6.6	3.5	.3	13.8	1.2	.5
2,000–2,999	9.8	7.6	2.7	.3	16.4	1.7	.9
Villages:							
Families of husband and wife with incomes of—							
500–999	9.4	3.3	2.6	.4	5.4	1.1	.3
1,000–1,499	7.7	5.5	2.3	.3	8.0	1.2	.3
1,500–1,999	9.1	7.3	2.8	.2	10.5	1.9	.5
2,000–2,999	8.8	5.6	2.7	.2	8.7	1.4	.4
Families of husband, wife, and 1 or 2 children under 16 years, with incomes of—							
500–999	12.6	4.5	3.0	.5	6.4	1.3	.4
1,000–1,499	12.5	5.8	3.0	.4	8.2	1.6	.4
1,500–1,999	11.0	7.6	3.6	.3	11.0	1.9	.4
2,000–2,999	11.0	7.9	3.1	.2	12.6	2.3	.5

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[1] White nonrelief families.

[2] From preliminary unpublished data, Bureau of Home Economics, Consumer Purchases Study.

[3] The following are approximately equivalent to the food value of 1 quart of fluid whole milk: (1) 17 ounces of evaporated milk; (2) 1 quart of fluid skim milk and 1½ ounces of butter; (3) 5 ounces of American Cheddar cheese; (4) 4½ ounces of dried whole milk; (5) 3½ ounces of dried skim milk and 1½ ounces of butter.

[4] See table 8, footnote 4.

[5] See table 8, footnote 5.

TABLE 10.—*City-family*[1] *food: Average per capita consumption in a year, by level of food expenditures, North Atlantic cities, 1931–37*[2]

Food items	Consumption[3] by families spending for food per capita per week averages[4] of about—				
	$1.60	$2.20	$2.80	$3.40	$4.00
Eggs ... dozen	13	19	23	28	36
Milk, whole, skim, buttermilk ... quarts	94	111	132	136	162
Milk, evaporated, condensed ... pounds	15	11	16	15	10
Cheese ... do	5	7	8	9	11
Cream, ice cream ... do	2	3	5	10	14
Total milk, fluids-not-fat equivalent[5] ... quarts	123	146	176	181	212
Butter ... pounds	14	19	23	25	31
Other table fats ... do	4	1	1	1	([6])
Cooking or salad oils, dressings ... do	4	5	7	9	8
Lard, other cooking fats ... do	5	7	9	7	8
Bacon, salt pork, suet ... do	3	4	5	6	7
Total fats ... do	30	36	45	48	54
Beef, veal ... do	41	48	64	61	75
Mutton, lamb ... do	6	6	12	19	26
Pork (exclusive of bacon and salt pork) ... do	15	21	30	33	48
Miscellaneous meat products ... do	8	10	12	11	14
Poultry ... do	4	11	16	26	28
Fish, other sea foods ... do	13	18	23	28	30
Total meat, poultry, fish ... do	87	114	157	178	221
Sugar ... do	46	52	59	63	72
Sirups, jellies, etc ... do	5	8	8	9	11
Bread, rolls ... do	116	121	128	139	145
Other baked goods ... do	16	26	35	47	45
Ready-to-eat cereals ... do	4	6	6	6	9
Other breakfast cereals ... do	26	21	22	23	24
Flours, meals ... do	26	29	32	26	35
Total flour equivalent[7] ... do	145	155	169	180	196
Potatoes, sweetpotatoes ... do	133	150	170	178	181
Dried legumes, cooked or canned ... do	6	7	9	8	6
Dried legumes and nuts ... do	8	7	9	9	8
Dried fruits ... do	3	4	6	7	12
Tomatoes ... do	19	25	34	38	38
Citrus fruits ... do	16	34	51	66	90
Leafy, green, and yellow vegetables[8] ... do	47	60	83	92	130
Other vegetables[8] ... do	29	40	56	80	72
Other fruits[8] ... do	50	86	105	138	162

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[1] Families of employed wage earners and low-salaried clerical workers.

[2] Adapted from U. S. Department of Agriculture Circular 507 (*1104*).

[3] Based on records for 1 week.

[4] Representative of expenditure ranges as follows: $1.25–$1.87; $1.88–$2.49; $2.50–$3.12; $3.13–$3.74; $3.75–$4.37. Adjusted to 1935 levels by use of U. S. Bureau of Labor Statistics index of retail food costs.

[5] See table 9, footnote 3.

[6] 0.5 pound or less.

[7] See table 8, footnote 5.

[8] Fresh and canned.

Table 11.—*City-family*[1] *food: Average per capita consumption in a year in five region-color groups, 1934–37*[2]

Food items	Consumption[3] by—				
	White families in cities of—				Negro families in southern cities
	North Atlantic region	East North Central region	Pacific region	East South Central region	
Eggs ... dozen	22	23	27	22	10
Milk, whole, skim, buttermilk ... quarts	122	109	126	98	30
Milk, evaporated, condensed ... pounds	14	13	24	21	11
Cheese ... do	8	9	11	5	2
Cream, ice cream ... do	5	5	11	1	1
Total milk, fluids-not-fat equivalent[4] ... quarts	162	144	188	138	51
Butter ... pounds	21	15	22	8	7
Other table fats ... do	1	6	5	7	3
Cooking or salad oils, dressings ... do	7	4	10	6	2
Lard, other cooking fats ... do	7	14	10	25	33
Bacon, salt pork, suet ... do	4	10	7	16	25
Total fats ... do	40	49	54	62	70
Beef, veal ... do	54	46	58	36	34
Mutton, lamb ... do	11	(5)	16	1	1
Pork (exclusive of bacon and salt pork) ... do	23	29	10	12	22
Miscellaneous meat products ... do	14	38	13	14	16
Poultry ... do	16	10	12	9	13
Fish, other sea foods ... do	21	9	19	11	40
Total meat, poultry, fish ... do	139	132	128	83	126
Sugar ... do	56	49	64	58	52
Sirups, jellies, etc ... do	8	13	16	19	14
Bread, rolls ... do	129	117	105	62	26
Other baked goods ... do	31	39	28	13	3
Ready-to-eat cereals ... do	6	7	6	4	(5)
Corn meal ... do	1	4	2	30	54
Rice ... do	4	3	3	4	15
Flour ... do	28	40	42	75	94
Other cereal products ... do	18	13	18	11	14
Total flour equivalent[6] ... do	164	170	160	175	196
Potatoes, sweetpotatoes ... do	157	138	139	100	91
Mature legumes, cooked or canned ... do	8	7	4	5	2
Mature dry legumes and nuts ... do	8	11	11	15	16
Dried fruits ... do	5	4	9	4	2
Tomatoes ... do	28	24	41	38	14
Citrus fruits ... do	43	39	86	26	6
Leafy, green, and yellow vegetables[7] ... do	74	60	122	81	91
Other vegetables[7] ... do	53	54	78	49	30
Other fruits[7] ... do	99	99	180	89	54

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[1] Families of employed wage earners and low-salaried clerical workers.
[2] Adapted from U. S. Department of Agriculture Circular 507 (*1104*).
[3] Based on records for 1 week.
[4] See table 9, footnote 3.
[5] 0.5 pound or less.
[6] See table 8, footnote 5.
[7] Fresh and canned.

TABLE 12.—*Specifications for diets rated good; daily allowances of calories and certain important nutrients*

Sex, age, and activity of individual	Energy	Protein	Calcium	Phosphorus	Iron	Vitamin A value[1]	Vitamin B_1	Vitamin C	Riboflavin
	Calories	*Grams*	*Grams*	*Grams*	*Milligrams*	*International Units*	*International Units*	*International Units*	*Sherman units*
Men, 20 years and over:									
Moderately active work	3,000	67	0.68	1.32	15	6,000	500	1,500	600
Very active work	4,500	67	.68	1.32	15	6,000	500	1,500	600
Light work	2,700	67	.68	1.32	15	6,000	500	1,500	600
Sedentary work	2,400	67	.68	1.32	15	6,000	500	1,500	600
Women, 20 years and over:									
Moderately active work	2,500	67	.88	1.32	15	6,000	500	1,500	600
Very active work	3,000	67	.88	1.32	15	6,000	500	1,500	600
Light work	2,300	67	.88	1.32	15	6,000	500	1,500	600
Sedentary work	2,100	67	.88	1.32	15	6,000	500	1,500	600
Boys:									
16–19 years	3,600	75	1.00	1.32	15	6,000	600	1,800	600
13–15 years	3,000	75	1.00	1.32	15	6,000	500	1,500	600
11–12 years	2,500	75	1.00	1.20	13	6,000	420	1,350	600
9–10 years	2,400	75	1.00	1.20	12	5,400	400	1,200	540
7–8 years	2,100	65	1.00	1.00	11	5,400	350	1,000	540
4–6 years	1,500	55	1.00	1.00	8	4,500	250	1,000	450
Girls:									
14–19 years	2,500	75	1.00	1.20	13	6,000	420	1,350	600
11–13 years	2,400	75	1.00	1.20	12	5,400	400	1,200	540
8–10 years	2,100	65	1.00	1.00	11	5,400	350	1,000	540
4–7 years	1,500	55	1.00	1.00	8	4,500	250	1,000	450
Children:									
2–3 years	1,200	45	1.00	1.00	6	4,500	200	1,000	450
Under 2 years	900	45	1.00	1.00	6	4,500	200	1,000	450

[1] From natural foods, exclusive of vitamin A concentrates.

PLANNING FOR GOOD NUTRITION

by Hazel K. Stiebeling and Faith Clark[1]

TO OBTAIN an adequate diet, it is necessary to apply the newer knowledge of nutrition to the daily selection of food. Here is a method for accomplishing this without, in many cases, having to spend an extra amount for food, and without violating personal tastes. The authors explain how to group foods so as to permit ample choice, how to plan a diet to fit the pocketbook, and how to figure the needs of different members of the family.

ONE of the main objects of modern biological science is to discover how we human beings can attain the greatest possible fitness and well-being within the limits of our inheritance. In this, nutrition is one of the biggest factors, since it is food that builds our bodies and gives us the energy we must have for everything we do. Much research has been conducted to discover what the nutritional needs of the body are and how they can be supplied. Enough has been learned so that fairly definite nutritional goals can now be set up for human beings. There are numerous gaps in our knowledge, and some things accepted as facts will undoubtedly have to be modified; yet in general it is now possible to outline what is needed in the way of food energy, protein supplies, minerals, and vitamins to keep the body fit, though this cannot be done as definitely for some of these essentials as for others.

The purpose of this article is to present some suggestions for diets based on the knowledge now available from the work of many scientists, and to do this in such a way that there will be as much opportunity as possible for individual choice, to allow for personal taste and for the size of the pocketbook. The size of the pocketbook is especially important, for the more limited the purse, the more difficult it is to provide enough of all the nutritive elements the body needs. To nourish a family adequately on a very small budget taxes all the wisdom and ingenuity of the homemaker; yet many homemakers accomplish it. Fortunately, it is possible to work out many different combinations of foods each of which will provide the same total quantity of nutrients.

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In selecting foods for such diets, five questions must be considered:

(1) What do families at different economic levels spend for food?

(2) How do different kinds or groups of foods rate as economical sources of required nutrients?

(3) What quantities of protective foods do people actually use in diets that can be rated as good, and can everyone afford these quantities?

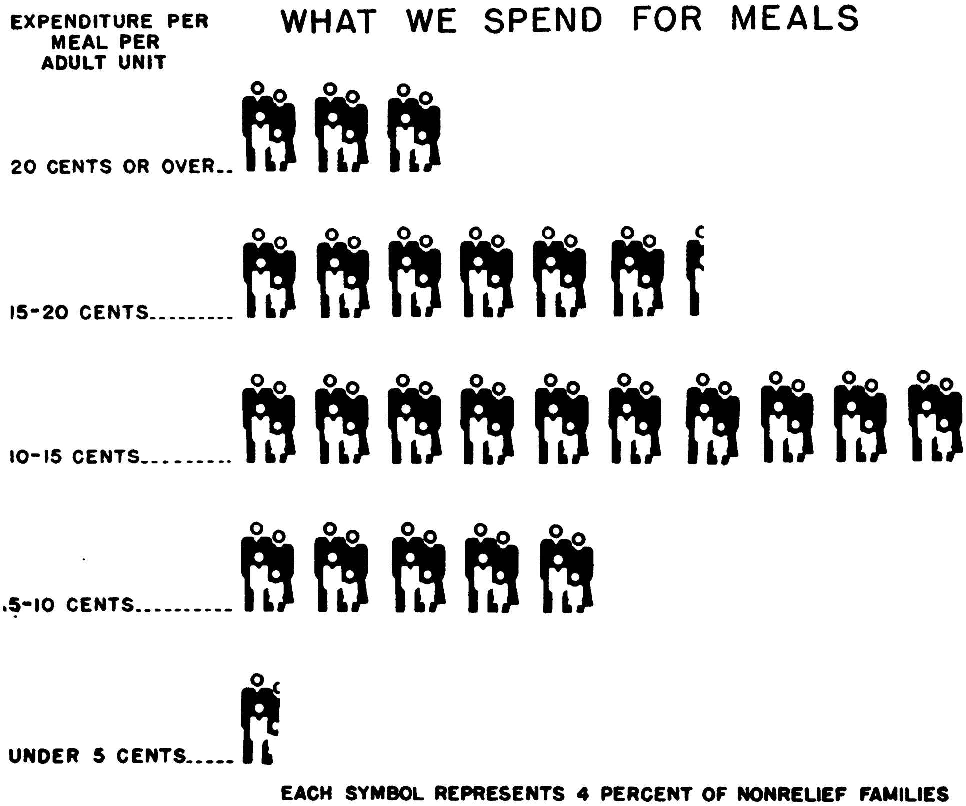

Figure 1.—More people in this country spend 20 cents or more per meal than are restricted to less than 5 cents, but nearly half (40 percent) spend amounts half-way between—10–15 cents per person per meal.

(4) What diets can be recommended in line with what people can afford?

(5) What is the range in costs of recommended diets in different parts of the United States?

WHAT FAMILIES SPEND FOR FOOD

What do families at different economic levels spend for food?

An extensive study made in 1936,[2] showed that about 1 out of every

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[2] Consumer Purchases Study, Bureau of Home Economics, data unpublished.

25 families not on relief ate less than 5 cents' worth of food a person[3] a meal for the meals taken at home. For about 25 percent of the families, the amount per meal was 5 to 10 cents; for another 40 percent, 10 to 15 cents; for 20 percent, 15 to 20 cents; and finally, 11 percent of families, or about one out of every 10, had 20 cents worth of food or more per unit per meal (fig. 1).

These calculations are based on the food prices of 1936. If the figures are adjusted to fit 1938 (January–October) prices, and all the families are divided into four equal groups, the conclusion is that the least prosperous one-fourth of nonrelief village and city families probably is spending less than $2.10 a week per food-expenditure unit for food; another fourth, $2.10 to $2.70; another fourth, $2.70 to $3.40; and the top fourth, $3.40 and more. In the case of nonrelief farm families, the food of the least prosperous one-fourth probably is valued[4] at less than $1.50 per unit per week; another fourth, $1.50 to $2; another fourth, $2 to $2.60; and the top fourth, $2.60 and more.

Thus few families in this country spend enough for food to be able to disregard economy in selection. Diets must be planned in the light of these actual expenditures.

ECONOMY AND NUTRIENTS

How do different kinds of foods rate as economical sources of required nutrients?

For the purpose of simplifying dietary problems, the foods common in this country can be classified into about a dozen major groups, each of which has fairly distinctive usefulness in the diet. The 12 groups are (1) milk; (2) potatoes and sweetpotatoes; (3) dry mature beans, peas, and nuts; (4) tomatoes and citrus fruits; (5) leafy, green, and yellow vegetables; (6) other vegetables and fruits; (7) eggs; (8) lean meat, poultry, and fish; (9) flours and cereals; (10) butter; (11) other fats; (12) sugars. Diets will differ not only in the quantities and proportions of the foods which represent each group, but also in the variety, form, and grades selected within each group. Although the nutritive values of the foods within a single group differ somewhat and the nutritive content of diets will be somewhat affected by choices within groups, yet foods within a group are more like each other than like those in other groups.

Each of these groups may be considered an economical source of certain nutrients. Figure 2 shows this graphically. It is based on the

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[3] Or more accurately, per food-expenditure unit per meal p. (303). The following scale may be used to determine family size in terms of food-expenditure (F. E.) units; that is, the approximate number of moderately active men that could be fed for the same sum:

	F. E. units
Men 20–74 years:	
Moderate work	1.00
Active work	1.12
Men 75 years and over	.92
Women 20 years and over:	
Moderate work	.92
Active work	1.02
Boys:	
16–19 years	1.13
13–15 years	1.10
11–12 years	1.00
Boys—continued.	
9–10 years	0.93
7–8 years	.85
4–6 years	.64
Girls:	
14–16 years	1.00
11–13 years	.93
8–10 years	.85
4–7 years	.64
Children 2–3 years	.57
Children under 2 years	.53

[4] To the cost of purchased food is added the worth of farm-furnished food valued at prices families would have paid had they bought similar quantities of food of comparable quality from neighbors or other likely sellers. Valued thus at less than city retail prices, more food is represented by a given sum than in cities or villages.

actual food purchases of city workers in the East North Central region in the spring of 1936—families spending $1.88 to $2.49 a person a week for food (*1104*).[5] Suppose 5 cents out of every dollar goes for items in one of these food groups. Then the black lines show how much of various nutrients that proportion of the total food expenditure will buy in terms of the percentage of the total purchases of each nutritive element. For instance, 5 percent of the total food expenditure going for milk, cheese, and ice cream bought 26 percent of the total calcium, 7 percent of the protein, and 14 percent of the riboflavin. Five percent spent for potatoes and sweetpotatoes supplied, among other things, about half of the vitamin C, and so on.

The following list shows this in another way. Here the food groups are placed under the nutritive elements instead of the nutritive elements under the food groups. A food group not marked with an asterisk furnished 5 to 9 percent of the total of that nutritive element for each 5 cents of the food dollar spent on it. A food group with one asterisk furnished 10 to 24 percent. A food group with two asterisks furnished 25 percent or more. Each food group may be considered an economical source of the nutritive element under which it is placed, but the double-asterisk groups are the cheapest sources of that particular nutrient, the single-asterisk the next, and the others the least cheap.

Calories

*Potatoes and sweetpotatoes
Mature dry beans, peas, nuts
Bread and ready-to-eat grain products
*Flour, meals, other cereals
Butter, cream
*Other fats
*Sugars

Protein

Milk, cheese, ice cream
*Potatoes, sweetpotatoes
*Mature dry beans, peas, nuts
Eggs
Meats, poultry, fish
Bread and ready-to-eat grain products
*Flour, meals, other cereals

Calcium

**Milk, cheese
Potatoes, sweetpotatoes
*Mature dry beans, peas

Iron

**Potatoes, sweetpotatoes
**Mature dry beans, peas
Leafy, green, yellow vegetables
Fruit, other than citrus
Eggs
Meats, poultry, fish
*Flour, meals, other cereals

Vitamin A value

Milk, cheese, ice cream
**Sweetpotatoes
*Tomatoes
**Leafy, green, yellow vegetables
Eggs
Butter, cream

Vitamin B_1

Milk, cheese, ice cream
**Potatoes, sweetpotatoes
**Mature dry beans and peas
Tomatoes, citrus fruit
Meats, poultry, fish

Vitamin C

**Potatoes, sweetpotatoes
**Tomatoes, citrus fruit
*Leafy, green, yellow vegetables
*Other vegetables
*Other fruits

Riboflavin

*Milk, cheese, ice cream
*Potatoes, sweetpotatoes
Eggs
Meats, poultry, fish

Thus in the total diet each food group may be thought of as an economical source of certain necessary nutritive elements.

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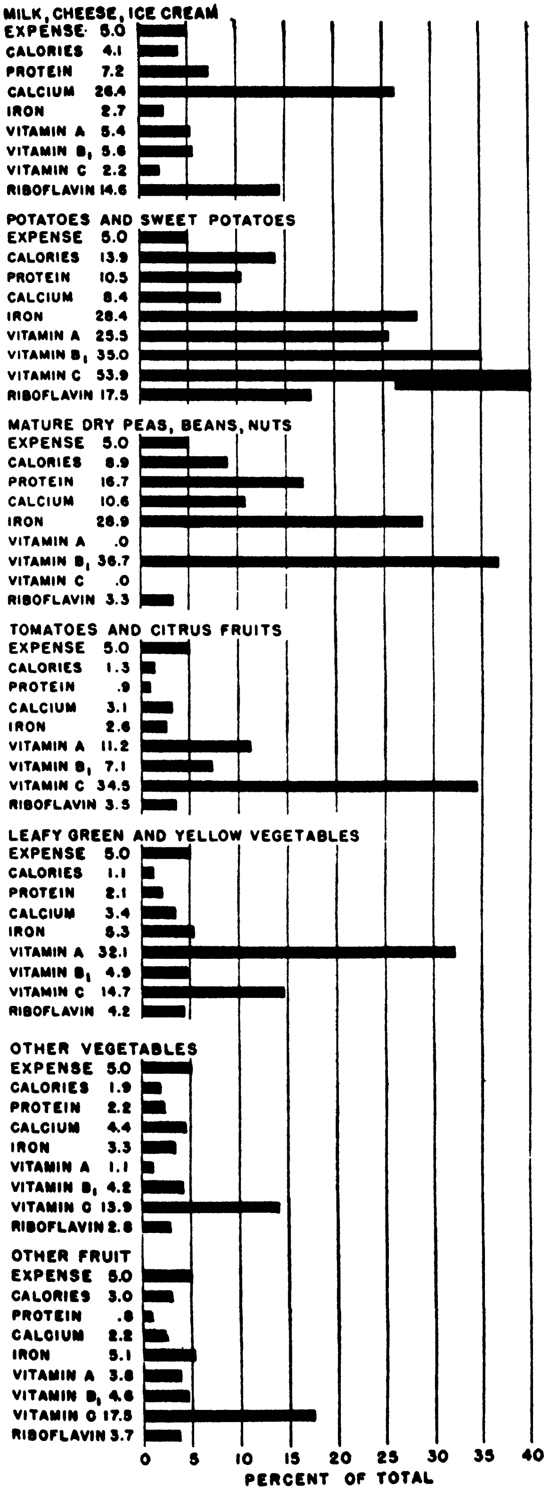
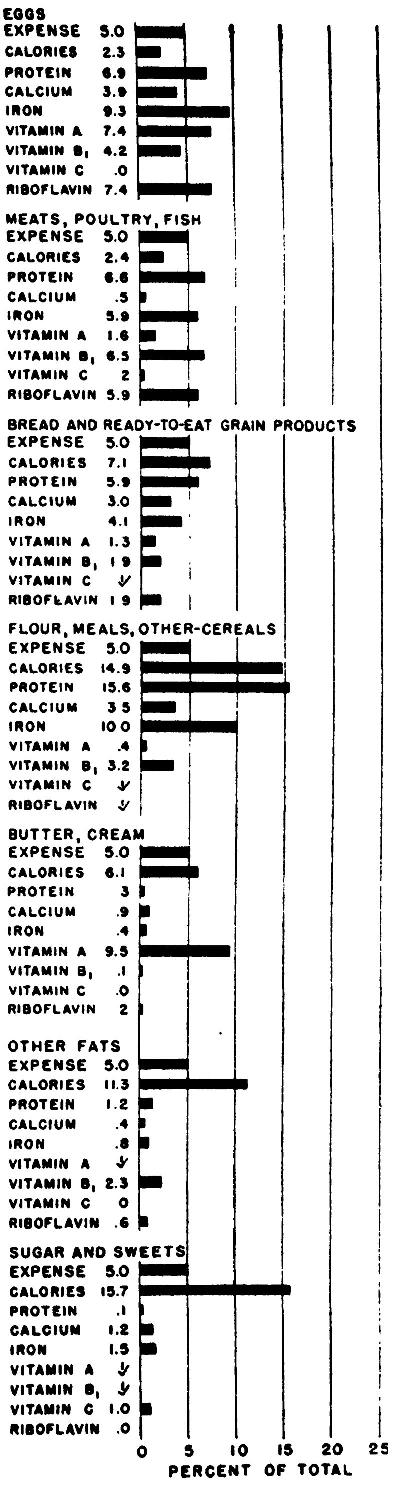
[5] Italic numbers in parentheses refer to Literature Cited, p. 1075.

***Figure 2.*—Percentage of total of specified nutrients contributed to the diet by different food groups when 5 percent of the food money was allocated to each. Families of city workers, East North Central region, spring 1936.**



√ 0.05 PERCENT OR LESS



√ 0.05 PERCENT OR LESS

CONTRIBUTIONS OF EACH FOOD GROUP TO THE DIET

Milk is a cheap and important source of protein, calcium, vitamin A value, vitamin B_1, and riboflavin. The forms in which it is taken—whether as cheese, or as fluid, evaporated, or dried milk—are largely matters of taste and relative cost. But without a generous supply of milk it is difficult to obtain the calcium needed for building and maintaining teeth and bones and for promoting a high level of general health. If skim instead of whole milk is used, extra butter or its equivalent in fat and vitamins A and D should be included in the diet. Whole-milk cheese furnishes practically the same food value as whole milk; 5 ounces of American Cheddar cheese has approximately the same food value as a quart of milk.

Vegetables and fruits in general are rather costly to produce and also to distribute, since they deteriorate easily in shipping, and their high water content means that they occupy much space in proportion to the nutritive value they carry. But they make outstanding contributions to the diet in minerals and vitamins, particularly vitamin C. They also help to maintain the alkaline reserve of the body, furnish roughage, and aid in maintaining good intestinal hygiene. They add variety in color, flavor, and texture to the diet.

Potatoes, sweetpotatoes, and mature dry beans and peas are comparatively cheap to grow, transport, and store. All furnish calories cheaply. Potatoes are especially valuable also for vitamins B_1 and C and for iron; sweetpotatoes, for vitamin A value; and mature beans and peas for protein, iron, and vitamin B_1.

Tomatoes and citrus fruits deserve special mention as a source of vitamin C. Since they can be served raw or with very little cooking, they help to protect the diet in this vitamin, which is readily destroyed by prolonged cooking.

The kinds of green leafy vegetables used for food differ greatly from one section of the country to another. The thinner and greener the leaf, the higher its value for iron and vitamin A tends to be. Aside from this consideration, it is economical to use the varieties common to a given locality because they are likely to be lowest in price. Turnip greens, kale, and collards are widely used in the South, and have about the same nutritive qualities as the beet tops, Swiss chard, and spinach that are more popular in the North. These vegetables play so important a part in diets of southern families, especially of the Negroes, that they might well be added with an asterisk to a list of foods important for calcium and riboflavin. Other green-colored vegetables, such as snap beans, peas, asparagus, and broccoli, are also valuable, though usually they are not so rich as the green leaves in vitamins and iron. Bleached leaves or stalks, such as those of blanched celery, certain types of lettuce, and hard-headed winter cabbage, are much poorer in vitamin A and iron than the green-colored ones.

Lean meat, fish, poultry, and eggs are highly prized for the interest and flavor they add to the diet. They have an important place, too, because their proteins are of excellent quality; they are rich in riboflavin, and they are pellagra-preventive. Eggs, liver, and lean meats are good sources of iron. Liver and eggs are also rich sources of vitamin A. But as sources of energy, meats, fish, and poultry are relatively expensive, and they tend to be deficient in calcium and vitamins A and C.

Fats, besides being cheap and important sources of fuel, are useful for the flavor and "staying" quality they give to foods. A certain quantity of unsaturated fatty acids appears to be nutritionally essential, and some fats, such as butter and fish-liver oils, are important carriers of the fat-soluble vitamins.

Flours, meals, and other grain products have always formed a large part of the food supply in most parts of the Temperate Zones throughout the world. The grains are easily and cheaply grown; they are cheap to distribute, since they occupy relatively little volume in proportion to food value; and they are comparatively easily protected against deterioration. They are especially important in low-cost diets because they are cheap sources of several nutritive values—calories, proteins, and iron. The less highly the grain is milled or refined, the more it contributes in minerals and vitamins, particularly in iron and vitamin B_1. Even when they are lightly milled, however, they are relatively deficient in calcium and in vitamins A, C, and D and riboflavin.

Sugar in ordinary commercial form also is a cheap fuel food, but it is a pure carbohydrate and contains none of the needed proteins, minerals, or vitamins. Cane and sorgo sirups contain considerable calcium and iron in addition to the carbohydrates.

Thus, some foods contribute more kinds of nutrients than others, and some provide certain food values more cheaply than others. Milk products, tomatoes, citrus fruit, and the green leafy vegetables—the protective foods—should be emphasized in diets at all economic levels because of their many-sided contributions, including unusual quantities of calcium, vitamin A, and vitamin C. If incomes are low, potatoes, mature dry beans and peas, and the grain products, especially in their cheaper and less highly refined forms, should be used in generous proportions. With greater purchasing power, the consumption of eggs, meats, and other vegetables and fruits may be increased beyond minimum quantities, in order to give the diet greater psychological appeal as well as physiological value. The flavorful sugars and fats are important as inexpensive sources of calories, but they should not displace nutritionally indispensable protective foods which safeguard diets in minerals, vitamins, and protein of high quality.

PROTECTIVE FOODS

What quantities of protective foods do people actually use in diets that can be rated as good, and can everyone afford these quantities?

Nutritionally, the difference between good diets and usual diets lies chiefly in the larger quantities of protective foods in the good diets. In table 1 are shown average quantities of eggs, dairy products, succulent vegetables, and fruit found in diets rated good[6] in the recent studies of family food consumption already referred to. Note that these are only the protective foods. They do not include all the foods in the diet.

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[6] See the article on Present-Day Diets in the United States for the definition of a good diet.

TABLE 1.—*Average quantities of protective foods a person a year in diets graded good, by families [1] living in communities of differing size, 1935–36* [2]

Size of community	Eggs	Milk or its equivalent [3]	Butter	Tomatoes, citrus fruits	Leafy, green, and yellow vegetables [4]	Other vegetables and fruits [5]
	Dozen	*Quarts*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Farm	28	330	23	90	180	285
Village	25	130	18	65	200	295
Small cities	35	240	23	175	150	315
Middle-sized cities	27	200	26	110	150	305
Large cities	32	200	20	140	150	310
Weighted average	30	225	21	115	165	300

[1] Native nonrelief families including both husband and wife.

[2] From preliminary unpublished data, Bureau of Home Economics, Consumer Purchases Study.

[3] Approximately equivalent to the food value of 1 quart of fluid whole milk are: 17 ounces of evaporated milk; 1 quart of fluid skim milk and 1½ ounces of butter; 5 ounces of American Cheddar cheese; 4½ ounces of dried whole milk; 3½ ounces of dried skim milk and 1½ ounces of butter.

[4] Sweetpotatoes not included.

[5] Potatoes, sweetpotatoes, and mature dry legumes not included; fresh fruit equivalent of dried fruits included.

The figures indicate that many different combinations of protective foods can be evolved which will meet or exceed a definite set of specifications in terms of nutrients. The average quantities of eggs ranged from 25 to 35 dozen a person a year; of milk, from 130 to 330 quarts; of butter, from 18 to 26 pounds; of tomatoes and citrus fruits, from 65 to 175 pounds; of leafy, green, and yellow vegetables, from 150 to 200 pounds; and of other succulent vegetables and fruits, from 285 to 315 pounds.

If neither the high nor the low, but rather an average figure is taken as representative, the list of protective foods would be as follows:

		Per capita per year
Eggs	dozen	30
Milk, or its equivalent	quarts	225
Butter	pounds	21
Tomatoes, citrus fruit	do	115
Leafy, green, yellow vegetables	pounds	165
Other vegetables and fruits	pounds	300

The combinations of protective foods—and other foods, too—in current diets rated good tend to be more expensive than can be afforded by the less prosperous half of the population. Taking as 100 the average outlay that probably is now made for protective foods by families in this country, the relative cost of the protective foods just listed amounts to 141.

It is necessary, then, to adjust the quantities of protective foods according to what people can afford to spend. Table 2 presents combinations of protective foods, arranged on this basis, that will safeguard most freely chosen diets. Again compared with 100 as representing the average outlay that is now afforded, the relative costs of these lists of protective foods, priced at identical market values per unit, are as follows:

Protective foods specified in plans for:	Relative cost
An economical fair diet	82
A low-cost good diet	112
A moderate-cost good diet	143
An expensive good diet	166

TABLE 2.—*Quantities of protective foods a person a year suggested for diets adapted to four economic levels*

Diet plan	Eggs	Milk or its equivalent [1]	Butter	Tomatoes, citrus fruits	Leafy, green, and yellow vegetables [2]	Other vegetables and fruits [3]
	Dozen	*Quarts*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
An economical fair diet	13	160	15	50	140	100
A low-cost good diet	17	230	20	65	160	130
A moderate-cost good diet	25	260	25	90	180	285
An expensive good diet	30	260	40	120	180	350

[1] See table 1, footnote 3.
[2] See table 1, footnote 4.
[3] See table 1, footnote 5.

McCollum (*722*) has said that a good diet should include the equivalent of a quart of milk every day throughout life; a liberal serving of greens or potherbs every day; twice each day a salad containing raw fruits or vegetables. The quantities of protective foods suggested in table 2 for the diets at four cost levels are somewhat less generous than McCollum's specifications. Nevertheless each represents a step in advance of present food-consumption habits at a comparable economic level. The more expensive diets furnish somewhat wider margins of safety in certain nutrients than do the cheaper diets. However, with average choices within each food group, the chances are high that the quantities of protective foods included in the three diets called "good" will be fully adequate nutritionally.

DIET PLANS

What diets can be recommended in line with what people can afford?

McCollum's rule (*722*), "Eat what you want after you have eaten what you should," may in general be followed in supplementing these budgets of protective foods to round out the daily menus. Habit, taste, and economy in nutritive values will affect the choices made. Food should be appealing as well as nourishing, but if circumstances call for strict economy, families should know when they are paying primarily for nutritive values and when for other satisfactions.

To help families in different economic groups to apply the principles of nutrition to their food supply, four diet plans are suggested in tables 4 to 7. (For the convenience of the reader, these are grouped together as an appendix to this article on pp. 337 to 340.) The quantities of food proposed for the economical fair diet, table 4, provide only a small margin of safety and hence may prove inadequate for individuals whose bodily requirements are far above average, or for any family if the nutritive values of the foods are much reduced through wasteful methods of storage or preparation. The suggestions for the three good diets in tables 5, 6, and 7 furnish, at three cost levels, a wide margin over and above average minimum requirements. As might be expected, the plans for good diets suggested for families of moderate and high incomes permit wider choice than those indicated for families with limited incomes.

These four diet plans are outlined in terms of the 12 major food groups already described. They are sufficiently broad that the foods

Figure 3.—In planning for home food production, the farm family can begin by figuring the quantities of certain foods they will need for good nutrition.

can be obtained in markets in any part of the country, or through the varied food-production programs possible in any of the different land-use areas (fig. 3). The forms, grades, and varieties of food selected within each group will be governed by family tastes, by the amount of money that can be spent for food, and by the possibilities of local production. Much of the satisfaction that a family will derive from its diet will depend upon the skill of the housewife in choosing, preparing, and presenting the food, taking into account special needs and family preferences as well as market or farm-furnished supplies.

In using any given diet plan, a family might follow these suggestions:

Write in the blank column provided in the table, beside the description that fits, the initials of every person who eats regularly with the family. If a description fits more than one person, write the initials of the extra person or persons on one or more of the blank lines, and copy the correct food quantities across the line. Next cross out the quantities of food having no one's initials beside them. Add the figures remaining in each column, and the totals form a yearly list for a balanced diet for the family.

The yearly quantities divided by 12 will give monthly figures, and divided by 50, somewhat more than is needed for a weekly list. Yearly or monthly figures are useful to farm families in planning programs of production and conservation. Weekly figures are more useful for current buying.

Diet plans should be treated as guides, not hard and fast rules. Between the maximum and minimum figures for any food group indicated in one plan or another, many combinations may be made. Thus, if vegetables and fruits are very plentiful or cheap, the quantities included in the moderate-cost or expensive diets may be substituted for those in the plan for the low-cost good diet. Or if meat and eggs can be home-produced or cheaply obtained, the quantities listed in the moderate-cost or expensive diets may be substituted for the quantities suggested in the low-cost diet. Thus, within limits, the plans may be combined or altered. Without expert guidance, however, it is unwise to reduce the quantities of eggs, milk, butter, vegetables, and fruit below those suggested in the economical fair diet plan (table 4), or to increase the quantities of grain products and potatoes above those listed in the same plan, or to increase the quantities of meat, sugar, and fats above those listed in the plan for the expensive good diet (table 7).

Occasionally there are special dietary needs not provided for in the general plan set up in the tables. These may be met by careful choices from available foods. For example, if more food energy must be supplied to persons doing exceptionally heavy work, or to very athletic growing youths, extra quantities of foods that are cheap sources of calories, such as potatoes, mature beans and peas, breads, cereals, fats, or sugars may be added to satisfy the need. Or if a child is large for his age and very active physically, the quantities listed for the next older age group may be followed instead of those listed for his age. Fortunately, the appetite is usually a good guide for needed fuel value and may be catered to after the minimal quantities of protective foods suggested in the general plans have been used to insure all-around dietary adequacy.

GOOD DIETS AT LOW AND MODERATE COSTS

These plans for low- and moderate-cost good diets are geared to the food-expenditure level of the middle half of the nonrelief families in this country. In 1938 this included city and village families that could afford from $2.10 to $3.40 per expenditure unit per week for food. Low-income farm families may wish to adopt the low-cost good diet if they can produce only a limited supply of their food at home, as in first years on the farm, or in general farming areas when crops are short, or in land-use areas poorly adapted to food production. Otherwise a plan as generous as the moderate-cost good diet or one even more liberal probably will be preferred by farm families.

When reduced incomes or rising food prices compel families to adjust to a cheaper food supply, such adjustments should first be sought in cheaper forms, varieties, or grades within food groups rather than in changes in the proportions of foods from the groups.

The specifications for the low-cost and moderate-cost good diets in terms of quantities of major groups needed by individuals are given in tables 5 and 6, pp. 338–339. Summarized, the plan for a good diet at low cost provides:

Milk (to drink or in cooked food):
- 3 to 4 cups daily for each child.
- 3 cups daily for each sedentary person.
- 1 quart daily for each expectant or nursing mother.
- 1 pint daily for each other adult.

Vegetables and fruits:
- Potatoes and sweetpotatoes—10 or 11 servings a week.
- Mature dry legumes and nuts—2 or 3 servings a week.
- Tomatoes and citrus fruits—4 or 5 servings a week (at least 4 to 6 tablespoons of tomato juice or 2 tablespoons of orange juice daily for each child under 4 years).
- Leafy, green, and yellow vegetables—9 or 10 servings a week.
- Other vegetables and fruits—9 or 10 servings a week.

Eggs: About 4 a week for each person.

Lean meat, fish, and poultry: 6 or 7 small servings a week.

Other foods:
- Cereal dish—usually once a day, sometimes twice.
- Bread—at every meal.
- Dessert—about once a day if desired.

The plan for the moderate-cost good diet provides:

Milk (to drink or in cooked food):
- 3 cups daily for each child under 2 years.
- 4 cups daily for each other child.
- 3 cups daily for each sedentary person.
- 1 quart daily for each expectant or nursing mother.
- 1 pint daily for each other adult.

Vegetables and fruits:
- Potatoes and sweetpotatoes—10 or 11 servings a week.
- Mature, dry legumes and nuts—1 or 2 servings a week.
- Tomatoes and citrus fruits—5 or 6 servings a week.
- Leafy, green, and yellow vegetables—10 or 11 servings a week.
- Other vegetables and fruits—2 or 3 servings a day.

Eggs: 5 or 6 eggs a week for each person.

Lean meat, fish, poultry: 7 or 8 servings a week.

Other foods:
- Cereal—daily.
- Bread—at every meal.
- Dessert—once a day, sometimes twice.

AN ECONOMICAL FAIR DIET

This plan for an economical fair diet is intended for village and city families in straitened circumstances or for low-income farm families that either have not yet established a good program of food production for home use or must buy all of their food because their food-production program has met with disaster.

If this plan, shown in table 4, is followed, the family will have a diet that more than covers average minimum requirements but does not afford as wide a margin of safety as is desirable, unless unusual precautions are taken in food selection. Also, it may not prove satisfactory from the standpoint of nutrition if any members of the family chance to have requirements decidedly higher than average, or if nutrients are wasted through poor methods of storage or preparation.

This economical diet provides:

Milk (to drink or in cooked food):
- 2 or 3 cups each day for children under 7 years.
- 2 cups daily for children 7 years and over.
- 1 quart daily for each expectant or nursing mother.
- 2 cups daily for each other woman and sedentary person.
- 1 cup daily for each man.

Vegetables and fruits:
- Potatoes and sweetpotatoes—10 or 11 servings a week.
- Mature, dry legumes and nuts—4 or 5 servings a week.
- Tomatoes and citrus fruits—3 or 4 servings a week (4 to 6 tablespoons of tomato juice or 2 tablespoons of orange juice daily for each child under 4 years).
- Leafy, green, and yellow vegetables—8 or 9 servings a week.
- Other vegetables and fruits—1 serving a day.

Eggs: 2 or 3 eggs a week for each person.

Lean meat or fish: 3 or 4 servings a week.

Other foods:
- Cereal dish—once or twice a day.
- Bread—at every meal.
- Dessert—occasionally, such as cereal pudding, gingerbread, dried fruit, one-egg cake, and other inexpensive kinds.

AN EXPENSIVE GOOD DIET

This diet plan, shown in table 7, is suggested for village and city families that do not have to count food dollars closely, and for farm families that can produce for home consumption generous quantities of milk, eggs, poultry, and meat, as well as vegetables and fruit.

This interesting, flavorful, but expensive good diet provides:

Milk (to drink or in cooked food):
- 3 cups daily for each child under 2 years.
- 4 cups daily for each other child.
- 3 cups daily for each sedentary person.
- 1 quart daily for each expectant or nursing mother.
- 1 pint daily for each other adult.

Vegetables and fruits:
- Potatoes and sweetpotatoes—1 serving daily.
- Mature, dry legumes and nuts—about 1 serving a week.
- Tomatoes and citrus fruits—1 serving daily.
- Leafy, green, and yellow vegetables—11 or 12 servings a week.
- Other vegetables and fruits—about 3 servings a day.

Eggs: 1 egg a day for each person.
Lean meat, fish, poultry: 9 or 10 servings a week.
Other foods: Cereals, bread, dessert, as desired.

MONEY VALUE OF THE FOUR PROPOSED DIETS

What is the range in costs of recommended diets in different parts of the United States?

With food prices constantly shifting, it is obvious that the cost or money value of any given diet may vary greatly from time to time. However, for purposes of comparison, the estimated money value per expenditure unit per week of each of the suggested diets is given below, as of January–October 1938 price levels:

Villages and cities:	
Economical fair diet	$1.50–$2.00
Low-cost good diet	1.85–2.90
Moderate-cost good diet	2.30–3.70
Expensive good diet	3.10–4.10
Farms:	
Economical fair diet	1.25–1.60
Low-cost good diet	1.60–2.00
Moderate-cost good diet	2.00–2.60
Expensive good diet	2.60–2.90

Comparing these figures with the amounts spent for food by nonrelief families (pp. 322–323), it is evident that the costs of the four diet plans correspond roughly to the food expenditures of the four groups of nonrelief families in this country. Probably the food expenditures of families on relief are fairly similar to those of the least prosperous quarter of nonrelief families.

The difference between farm costs and village and city costs is due to the large amount of home-produced food which makes up the farm family's diet and which has been valued at less-than-city prices, as previously explained (footnote 4, p. 323).

The range in costs given for each diet plan has two explanations. The first and more important is that families in various parts of the country make different choices of items within each food group. The second is that the retail prices of these foods may vary from region to region. Since the second factor is less important in its effect on the unit price of a food group than the first, much less variation in the costs of the diets would be apparent if the diets were priced region by region using an identical list of choices within each food group.

Differences both in the assortment of items selected within food groups and in the retail prices of different articles lead to variations in the average cost per market unit for different food groups. This is illustrated in table 3, which shows average prices paid by families of wage earners and low-salaried clerical workers in 1934–37 (*1104*). No information is available as to the market quality of the food represented by these prices, or regarding other influences affecting prices. Most of the unit prices refer to groups of food with similar though not identical nutritive value, rather than to individual items. For an individual item such as eggs, the regional price differences at each season reflected differences in market quality and in production or handling charges.

TABLE 3.—*Average prices reported per unit of specified food groups by families of employed workers in cities, classified by level of expenditure, color of family, and region, December 1934–February 1937*[1]

Weekly per capita expenditure for food, color of family, and region	Milk or its equivalent[2] (quart)	Potatoes, sweetpotatoes (pound)	Mature beans, peas, nuts (pound)	Tomatoes, citrus fruits (pound)	Leafy, green, and yellow vegetables (pound)	Other vegetables and fruits (pound)	Eggs (dozen)	Lean meats, poultry, fish (pound)	Fats, including butter (pound)	Flour, meals, cereals[3] (pound)	Sugars (pound)
$1.25–$1.88:											
White:	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*
North Atlantic	10.3	1.6	11.5	8.5	7.2	6.2	32.1	22.4	25.9	11.5	6.3
Pacific	10.1	1.6	11.2	7.9	6.6	6.0	29.7	20.8	25.0	11.4	6.8
East South Central	9.2	2.2	10.2	6.4	5.7	5.4	29.8	19.5	20.9	7.9	7.5
Negro:											
South	9.9	2.4	7.3	7.1	4.0	4.6	27.9	15.8	19.5	5.9	7.0
$2.50–$3.13:											
White:											
North Atlantic	11.2	1.8	12.0	8.0	7.5	6.7	35.9	26.4	28.0	13.8	7.2
Pacific	10.1	2.3	13.2	5.7	5.7	6.1	29.4	21.9	28.3	13.2	8.0
East South Central	9.9	2.5	11.6	6.4	6.4	6.2	32.6	24.1	23.0	10.4	8.1
Negro:											
South	9.9	2.2	11.4	6.7	4.2	3.4	31.5	19.6	22.7	6.7	6.7

[1] From U. S. Department of Agriculture Circular 507 (*1104*).
[2] See table 1, footnote 3.
[3] Includes flour purchased in form of baked goods.

In the case of food groups including two or more articles of food differing in retail price per market unit, the average price is affected by the proportion of the more expensive foods included in the total quantity. Whereas the price of whole fresh milk in cities studied in the Southeast was 12.6 cents per quart, as compared with 11 and 12 cents in the North Atlantic and Pacific regions, southern families spending $1.25 to $1.88 a person a week for food paid an average of only 9.2 cents per quart for fluid milk or its equivalent in other forms. This was lower than was paid by families at the same economic level in other regions because larger proportions of the less expensive forms of milk, such as evaporated milk and buttermilk, were used in the Southeast than elsewhere.

The average price paid for potatoes and sweetpotatoes was higher in the South than in the North. This was partly because a larger proportion of sweetpotatoes was used in the South, where they were slightly more expensive than potatoes, and partly because potatoes also were higher priced in southern than in northern markets.

For leafy, green, and yellow vegetables as well as other vegetables and fruits, average prices paid in the South, particularly by the Negroes, were less than in other regions. Southern families commonly selected inexpensive locally grown foods, such as collards, kale, mustard and turnip greens, and okra. Nevertheless, the nutritive value of these cheaper vegetables was as high as or higher than the nutritive value of the more expensive vegetables selected by northern families.

Northern families paid comparatively high prices for meats. They bought a large proportion of rather expensive tender cuts, such as steaks, roasts, and chops. These cuts may be cooked quickly by methods that develop highly prized flavors, but there is little difference in the nutritive values of the edible portions of different cuts of muscle meats. In the South cheaper cuts of pork and beef were consumed. Negro families tended to use more poultry and fresh fish than did white families.

Prices paid for fats by families in the South were lower than those in other regions, because a smaller proportion of the fats bought by southern families was in the form of butter and a larger proportion was in the form of shortenings and fat meats. This choice resulted also in a reduction of the vitamin A obtained from fatty foods. However, southern families compensated for this in a large measure by choosing large quantities of the vitamin A-rich green, leafy, and yellow vegetables.

Families of the North and West increased their expenditures for grain products by choosing many in highly processed forms, such as baked goods and ready-to-eat cereals. Southern families bought more flour and corn meal for biscuits and quick breads, and more rice and hominy, bringing the average cost per pound to half or less than half of that paid by families of the North and West.

These few examples indicate how the prices paid per market unit for foods similar in nutritive value may differ from one part of the country to another. As a result of differences in habitual selections within various food groups, city families might pay as little as $1.85 per expenditure unit per week or as much as $2.90 even when following the same general low-cost diet. Thus, the costs of the recommended diets in different parts of the United States will vary according to the habitual selection of foods by the family and to any regional differences in food prices.

The figures given on the costs of the suggested diets are valuable chiefly for comparative purposes. Given favorable market conditions, intelligent, thrifty families might buy these diets for less. Many will spend more. But the point should be emphasized that families can be expected to obtain nutritionally satisfactory diets when spending moderate or small sums for food only if they follow guides such as those outlined in this article. When they spend equal sums in accordance with prevailing food choices, the chances are that the resulting diets will be in need of improvement in one or more nutrients.

Only an application of the newer knowledge of nutrition to daily food selection can bring the goal of dietary adequacy within the reach of all.

APPENDIX—DIET TABLES

TABLE 4.—*An economical fair diet*

Family members		Kinds and quantities of foods for a year											
Name	Description	Milk	Potatoes, sweet-potatoes	Mature dry legumes, nuts	Tomatoes, citrus fruits	Leafy, green, yellow vegetables	Other vegetables, fruits	Eggs	Lean meat, poultry, fish	Flour, cereals	Butter	Other fats	Sugars
		Quarts	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Dozen*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
	Children under 2 years	260	80		50	80		18		50	7		3
	Children 2 to 3 years	180–260	100	3	50	120	30	18	10	100	10		10
	Boys:												
	4 to 6 years	180–260	120	10	50	120	40	15	20	120	15	3	20
	7 to 8 years	180	130	20	50	160	75	15	40	180	15	15	30
	9 to 10 years	180	140	25	50	160	100	15	50	210	15	25	40
	11 to 12 years	180	140	25	50	160	120	13	65	230	15	25	50
	13 to 15 years	180	160	25	50	120	150	13	70	270	15	40	65
	16 to 19 years	180	220	25	50	100	130	11	80	365	15	50	65
	Girls:												
	4 to 7 years	180–260	120	10	50	120	40	15	20	120	15	3	20
	8 to 10 years	180	130	20	50	160	75	15	40	180	15	15	30
	11 to 13 years	180	140	25	50	160	100	15	50	210	15	25	40
	14 to 19 years	180	140	25	50	160	120	13	65	230	15	25	50
	Men 20 years and over:												
	Very active	90	300	50	50	100	130	11	100	440	15	65	80
	Moderately active	90	160	40	50	120	150	11	80	270	15	30	65
	Sedentary	180	140	25	50	160	140	13	65	210	15	25	40
	Women 20 years and over:												
	Very active	180	160	25	50	160	150	13	80	270	15	30	65
	Moderately active	180	140	25	50	160	120	13	65	230	15	25	50
	Sedentary	180	100	15	50	160	140	13	65	160	15	25	40
	In pregnancy	365	140	15	50	200	165	15	65	200	15	25	40
	In lactation	365	180	15	50	200	175	15	65	250	15	30	50
Yearly total for family													
Monthly total (divide by 12)													
Weekly total (divide by 50)													

TABLE 5.—*A low-cost good diet*

Family members		Kinds and quantities of foods for a year											
Name	Description	Milk	Potatoes, sweet-potatoes	Mature dry legumes, nuts	Tomatoes, citrus fruits	Leafy, green, yellow vegetables	Other vegetables, fruits	Eggs	Lean meat, poultry, fish	Flour, cereals	Butter	Other fats	Sugars
		Quarts	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Dozen*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
	Children under 2 years	260	80		65	80		18		50	7		3
	Children 2 to 3 years	365	90		65	130	40	22	15	80	10		7
	Boys:												
	4 to 6 years	365	100	7	65	130	75	22	25	100	15		15
	7 to 8 years	260–365	120	10	65	180	100	22	65	140	20	3	25
	9 to 10 years	260–365	130	10	65	200	140	18	80	160	20	20	40
	11 to 12 years	260–365	140	15	65	200	140	18	90	180	20	20	40
	13 to 15 years	260–365	160	15	65	160	175	18	100	230	20	30	50
	16 to 19 years	260–365	220	15	65	160	175	13	140	310	20	40	65
	Girls:												
	4 to 7 years	365	100	7	65	130	75	22	25	100	15		15
	8 to 10 years	260–365	120	10	65	180	100	22	65	140	20	3	25
	11 to 13 years	260–365	130	10	65	200	140	18	80	160	20	20	40
	14 to 19 years	260–365	140	15	65	200	140	18	90	180	20	20	40
	Men 20 years and over:												
	Very active	180	300	25	65	160	175	13	160	420	20	60	80
	Moderately active	180	160	20	65	160	175	13	130	230	20	30	65
	Sedentary	260	140	10	65	180	140	18	90	160	20	20	40
	Women 20 years and over:												
	Very active	180	160	15	65	180	175	18	100	230	20	30	65
	Moderately active	180	140	15	65	180	165	18	90	180	20	20	50
	Sedentary	260	100	10	65	180	140	18	90	120	20	20	40
	In pregnancy	365	140	10	65	250	200	22	90	170	20	20	40
	In lactation	365	170	10	65	250	200	22	100	210	20	30	50
Yearly total for family													
Monthly total (divide by 12)													
Weekly total (divide by 50)													

TABLE 6. *A moderate-cost good diet*

Family members		Kinds and quantities of foods for a year											
Name	Description	Milk	Potatoes, sweet-potatoes	Mature dry legumes, nuts	Tomatoes, citrus fruits	Leafy, green, yellow vegetables	Other vegetables, fruits	Eggs	Lean meat, poultry, fish	Flour, cereals	Butter	Other fats	Sugars
		Quarts	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Dozen*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
	Children under 2 years	260	50		80	80		18		40	7		3
	Children 2 to 3 years	365	90		80	130	100	26	20	65	10		7
	Boys:												
	4 to 6 years	365	100	3	80	130	135	30	40	80	15		15
	7 to 8 years	365	100	7	80	180	180	30	80	100	25		25
	9 to 10 years	365	120	7	90	200	240	30	100	130	25	15	40
	11 to 12 years	365	130	7	90	200	280	26	130	130	25	15	40
	13 to 15 years	365	160	15	100	160	365	26	140	170	25	25	50
	16 to 19 years	365	220	15	100	160	410	22	160	200	25	55	80
	Girls:												
	4 to 7 years	365	100	3	80	130	135	30	40	80	15		15
	8 to 10 years	365	100	7	80	180	180	30	80	100	25		25
	11 to 13 years	365	120	7	90	200	240	30	100	130	25	15	40
	14 to 19 years	365	130	7	90	200	280	26	130	130	25	15	40
	Men 20 years and over:												
	Very active	180	300	15	100	160	390	22	200	300	25	75	100
	Moderately active	180	160	10	100	160	330	22	160	180	25	40	65
	Sedentary	260	130	7	90	180	210	26	130	120	25	15	40
	Women 20 years and over:												
	Very active	180	160	15	100	210	365	26	160	170	25	40	65
	Moderately active	180	130	7	90	210	280	26	130	140	25	25	50
	Sedentary	260	90	7	90	180	210	26	130	80	25	15	40
	In pregnancy	365	130	7	90	250	325	30	130	130	25	15	40
	In lactation	365	160	7	100	250	380	30	130	160	25	40	50
Yearly total for family													
Monthly total (divide by 12)													
Weekly total (divide by 50)													

TABLE 7.—*An expensive good diet*

Family members		Kinds and quantities of foods for a year											
Name	Description	Milk	Potatoes, sweetpotatoes	Mature dry legumes, nuts	Tomatoes, citrus fruits	Leafy, green, yellow vegetables	Other vegetables, fruits	Eggs	Lean meat, poultry, fish	Flour, cereals	Butter	Other fats	Sugars
		Quarts	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Dozen*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
	Children under 2 years	260	50		80	80		18		40	7		3
	Children 2 to 3 years	365	80		80	130	150	26	20	50	10		7
	Boys:												
	4 to 6 years	365	90		80	130	225	30	40	65	15		15
	7 to 8 years	365	100	3	90	180	290	30	90	80	25		25
	9 to 10 years	365	100	3	100	200	330	30	130	80	40		40
	11 to 12 years	365	120	3	120	200	360	30	160	80	40		40
	13 to 15 years	365	160	7	130	180	420	30	200	100	40	10	50
	16 to 19 years	365	220	7	130	180	470	30	250	130	40	40	80
	Girls:												
	4 to 7 years	365	90		80	130	225	30	40	65	15		15
	8 to 10 years	365	100	3	90	180	290	30	90	80	25		25
	11 to 13 years	365	100	3	100	200	330	30	130	80	40		40
	14 to 19 years	365	120	3	120	200	360	30	160	80	40		40
	Men 20 years and over:												
	Very active	180	300	7	130	180	450	30	250	230	40	60	100
	Moderately active	180	160	7	130	180	400	30	210	120	40	25	65
	Sedentary	260	120	3	120	200	325	30	130	90	40		40
	Women 20 years and over:												
	Very active	180	160	3	130	210	400	30	200	120	40	25	65
	Moderately active	180	120	3	120	210	340	30	160	90	40	10	50
	Sedentary	260	80	3	120	200	325	30	130	65	40		40
	In pregnancy	365	120	3	120	250	380	30	160	90	40		40
	In lactation	365	130	3	130	250	425	30	200	120	40	25	50
Yearly total for family													
Monthly total (divide by 12)													
Weekly total (divide by 50)													

MICRO-ORGANISMS IN FOODS AND FOOD PRESERVATION

by Harry E. Goresline[1]

BACTERIA, yeasts, and molds cause enormous losses in the food industries every year, attacking and spoiling practically every kind of food. Preventing this loss is one of the most important problems in our modern economy. It can be done only by using correct methods and continual care. In this brief account, the author tells how such spoilage occurs and outlines what is done to prevent it. He also describes the use of micro-organisms for making many products, including such everyday foods as bread and cheese.

THE MICRO-ORGANISMS that act on foods may be divided into two general groups: (1) Those bringing about spoilage and deterioration, and (2) those employed by man as a means of preservation.

Bacteria, yeasts, and molds are microscopic forms of plant life that utilize the soluble constituents of food in their life processes, or that secrete enzymes that bring about decomposition of food tissue, which renders many of the constituents soluble and available to the micro-organisms. These processes are going on in nature continuously, and they account for a large proportion of the decomposition of organic matter to material which increases the fertility of the soil. The decay of leaves, wood, grass, etc. is brought about by these minute forms of life.

Bacteria, yeasts, and molds cause enormous losses in the food industries. Since these micro-organisms are everywhere in nature, they are present on the surface of nearly all fresh food products. As long as the plant or animal is alive and in good condition it has the ability to prevent the action of the micro-organisms on its tissues, but if the healthy condition of the organism is lowered or the plant or animal is killed, then the micro-organisms gain access to the tissue and decomposition results.

For example, an apple hanging on the tree is ordinarily free of decay although bacteria, yeasts, and molds are present on its surface. Like most fruits it has a waxy coating, which protects it from invasion, but once this is removed or the surface broken or bruised the micro-organisms gain access and begin to destroy the tissue. When this apple is picked and placed in storage certain natural changes begin that soften and mellow it and bring it to the stage called ripe. If the apple is left in storage long enough, or has been bruised, its resistance to the invasion of micro-organisms will be lowered to the point where some form of rot will set in. This invasion of the tissue is generally made by some form of mold, which, by enzymatic action, softens the tissue and makes it relatively easy for bacteria and yeasts to gain entry. Within a very short time the apple is reduced to a dark, soft, mushy mass of soluble material. It is by this process that nature prevents the accumulation of insoluble organic material that would otherwise clutter up the earth.

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PROTECTION AND STORAGE OF FOODS

FRUIT

In common with other forms of life, micro-organisms grow best under certain conditions of acidity, oxygen supply, and carbohydrate and nitrogen metabolism. Since most fruits are acid, they are attacked principally by molds and yeasts, which are acid-tolerant and grow best under acid conditions. Bacterial spoilage of fruit is of secondary importance. Pectin, starch, and other carbohydrates are broken down by these micro-organisms, and the fruit becomes soft, unsightly, and unfit for consumption. Even in the early stages of the decomposition, it becomes unpalatable.

A number of methods have been devised to prevent spoilage of fruit in storage. Cold storage is used almost universally for the preservation of fruit and fruit products. Low temperatures retard the natural processes in the fruit and retard the growth of micro-organisms. Waxy or fungicidal coatings are applied to the surface of fruits, especially citrus fruits, and fungicidal wrappings have also been used on various kinds of fruits.

FRUIT JUICES

Freshly pressed fruit juices contain many micro-organisms that quickly multiply unless some preservation process is employed. The surface of the juice generally becomes covered with a white to gray wrinkled scum of mycoderma, which destroys the fruit acids and the sugars and gives rise to musty flavors. Since the scum must have access to oxygen in order to grow, one method of preventing this surface growth is to seal the juice from the air. A cottony type of mold also may form on the surface of fruit juices that are not sealed from the air.

Yeasts multiply quickly in fresh fruit juices and convert the sugars to alcohol and carbon dioxide. Under controlled conditions the juices are converted into wines by this process, but in open containers a large amount of acetic acid is formed. This fermentation and acetification make fruit juices unfit for consumption in a short time. The preservation of the juices may be accomplished by pasteurization, filtering to remove all germs, or freezing. The process most universally employed is pasteurization, in which the juice is either heated in bulk and bottled hot, or heated in the bottle. The temperature and method employed are different for each juice owing to the differences in acidity, sugar content, and initial contamination with micro-organisms. Freezing prevents fermentation, but this process starts as soon as the juice is thawed.

VEGETABLES

Fresh vegetables differ in composition and character from fruits, and naturally the flora of the surface and manner of spoilage are somewhat different. Most vegetables are nonacid, and many types of bacteria and other micro-organisms will grow on the surface and in the tissue that will not grow on fruits. Bacteria and molds growing on vegetables break down the pectic material, and the tissue becomes soft and watery through loss of structure. If piled together, most vegetables undergo a sweat with a considerable rise in temperature. This steamy, warm environment is ideal for the growth of many micro-organisms and spoilage of the product takes place in a few hours. Fresh vegetables should be handled rapidly, kept as cool as possible, and not placed in large containers or piles. Ample circulation of air should be afforded in any storage place.

Certain bacteria convert the soluble sugars present in the vegetables to lactic acid, which gives the product a sour smell and taste. This souring takes place in fresh and cooked vegetables, as well as in thawed frozen products, and should be used as one criterion in judging when material is fit for consumption.

FROZEN FOODS

In the last few years the increased production and consumption of frozen foods, including ice cream, meat, fish, poultry, eggs, fruits, and vegetables, has renewed interest in the action of micro-organisms at low temperatures. Thirty-two degrees Fahrenheit has not proved sufficiently low to prevent growth over prolonged storage periods of many bacteria, yeasts, and molds capable of bringing about changes in appearance, flavor, texture, and general usability of the stored foods. Storage at temperatures above 15° F. is not considered safe from the standpoint of microbial spoilage, nor is this temperature sufficiently low to prevent undesirable enzymatic changes in certain products. The rate of destruction of microbes and the predominating forms surviving are determined by such factors as rate of freezing, the nature of the product, acidity, size and type of container, airtightness of the pack, subfreezing storage temperature, length of storage, original contamination, etc. Less resistant microbial forms are destroyed during the first intervals of freezing. Thereafter the rate of destruction is slow. Some microbial forms may remain viable for several years.

Most spoilage encountered in the frozen-food industry is due to improper handling of the product prior to freezing or after it is thawed. Vegetables are scalded (blanched) before being frozen to inactivate the enzymes present in the tissue, and during this process many micro-organisms are killed by the heat. If vegetables are held for a time before scalding or freezing, there is danger of the growth of micro-organisms that will produce lactic acid, musty flavors, softening of the tissue, and general loss of quality. Frozen-food products are not sterile, but their microbial content may be kept low by sanitary preparation and handling, by the maintenance of subfreezing temperatures below which microbial growth is known not to take place, and by immediate use of the product after thawing.

As soon as the frozen food is thawed and left at room temperature the micro-organisms start to grow. Owing to the partial cooking of such vegetables during the scalding process, the tissue is softer than that of fresh vegetables and the product will sour in a very few hours unless it is kept cold.

Fruits are generally packed in sirup or dry sugar just before they are frozen. Yeast growth starts quickly both in material to be frozen and in that which has been thawed. Mold growth is to be expected on portions exposed to the air, and the combined action of the micro-organisms and the oxygen of the air give rise to darkening and to off flavors and odors in unfrozen material.

Fish to be frozen should be handled rapidly, and only freshly caught fish should be used, for decomposition sets in rapidly. Even though they may look fairly acceptable in the frozen state, products of low initial quality will have undesirable odors and flavors when thawed.

To secure and maintain high quality in frozen food it is necessary to start with high-grade material, handle it rapidly under sanitary conditions, store and transport at proper freezing temperatures, and use it within a short time after thawing.

CANNED FOODS

In the canning process foods are packed in hermetically sealed containers, and the enzymes are inactivated and the spoilage micro-organisms killed by the action of heat. When improper processing is employed certain micro-organisms survive and multiply in the product. Certain types of bacteria produce gas that swells the ends of the cans. Other types produce acid without producing gas; this type of spoilage is referred to as "flat sour." Canned food that shows evidence of spoilage or has an off odor or flavor should be discarded.

Molds do not grow in the absence of air, but yeasts may ferment fruits that are improperly processed and cause spoilage. Yeast fermentation produces carbon dioxide and swells the cans. The time and temperature of processing have been worked out in commercial practice for the various food products until there is relatively little spoilage.

EGGS

Much of the spoilage and deterioration encountered in fresh, stored' and processed eggs are due to micro-organisms. The presence of large numbers of micro-organisms is an indication of improper handling and often of unsanitary conditions. A certain percentage of eggs contain bacteria at the time they are laid, but most eggs are sterile. The white of the egg contains a product known as lysozyme, which kills bacteria and which no doubt accounts for much of the freedom from contamination.

If the flock is handled in such a way as to produce a large percentage of "dirties," or the eggs are subjected to improper treatment, a much higher loss from bacterial spoilage is to be expected. The principal types of bad eggs found during and after storage are green whites, digested whites, white rots, and black rots. As a rule these types show decided chemical decomposition and are heavily infected with bacteria. Owing to their high nitrogen and sulfur content, eggs have very bad odors and flavors when decomposed by bacteria. Musty eggs also are caused by bacterial growth. In commercial practice nearly all infected eggs are detected by candling so that few bad eggs reach the consumer.

The molding of the surface of eggs in storage gives them an unsightly appearance, but this trouble can be avoided by proper handling. If the humidity is properly controlled and contaminated cases and packing materials are eliminated, very little trouble should be encountered. Such molding does not affect the food value of the egg unless it is allowed to remain in storage for a considerable length of time, in which case the mold will penetrate the shell and cause darkening.

Rigid sanitary measures are essential in egg-breaking plants if quality products are to be produced. Great care should be exercised in breaking to eliminate all bad eggs, since whole batches can become infected by one musty egg accidentally included through careless inspection. This musty flavor or odor is very penetrating, and every precaution should be employed to keep such materials out of the commercial pack. The eggs should be broken separately, examined, and smelled before being added to the main batch in the mixer.

Speed is essential in handling eggs to be frozen. The fresh eggs should be kept in cold storage until ready for breaking. As soon as they are broken they should be churned, poured into the final containers, and frozen as rapidly as possible. If any chance is given for bacteria to multiply in the egg mass there is likelihood of the production of off flavors and odors and of general loss of quality.

MILK

Milk is a highly perishable article of food, chiefly because it is an ideal medium for the growth of micro-organisms. The souring of milk is a well-known example of this activity. Certain bacteria convert the milk sugar to lactic acid, and under ordinary conditions at room temperature this process is carried on very rapidly. When a certain acidity has been reached the casein is converted to its insoluble state and sets in the form of curd. Bacteria of the *Bacillus subtilis* type produce a rennetlike enzyme which forms sweet curdling of milk, but later the curd is more or less completely digested. The growth of undesirable micro-organisms often gives rise to very objectionable odors, soapy or bitter flavors, and various abnormal colors, or they may produce gums in the milk. Yeasts may grow in cream and cause it to "gas" or become frothy. Pasteurization is generally employed to kill the bacteria, and it greatly prolongs the time that milk may be kept in wholesome and palatable condition. Cold storage should be used wherever possible to retard the growth of the micro-organisms in milk, and needless to say, every sanitary precaution should be taken in handling.

MEAT

If meats are handled rapidly under sanitary conditions and the proper cold-storage methods are employed, relatively little microbiological spoilage should occur. A bacterial infection next to the bone known as "ham souring" or "bone souring," which has caused considerable difficulty, is due without doubt to slow withdrawal of animal heat or to improper penetration of brine. Injuries to the bone and tissue during slaughter may play an important role. Beef souring is also sometimes encountered. Under certain conditions of humidity, long cold storage, and contamination in handling, fresh meat may become covered with a growth of mold, but this is of little consequence unless it affects the appearance of the product. Under conditions of improper handling and storage, bacteria and molds may produce putrefaction and thus render the product unfit for human consumption. Salting, smoking, drying, and freezing are employed to prevent bacterial action, retard enzyme activity, and reduce possibility of rancidity.

CARBOHYDRATE MATERIALS

Bacteria, yeasts, and molds seldom develop in sugar, starch, or sirups, because of lack of moisture. However, certain types of food-spoilage bacteria sometimes occur in carbohydrates, and when the carbohydrates are added to canned foods they may cause spoilage unless extreme care is taken to safeguard the keeping quality. This group of bacteria is known as "thermophilic," which means "heat loving." The optimum temperature for growth is about 131° F., which is well above the temperatures tolerated by most forms of bacteria. The spores of this group are highly resistant to heat and are not easily killed during the normal processing of food products. Spoilage of processed foods by this group of bacteria usually results from undercooling after processing or from storage in too warm places.

The manufacturers of sugar are cooperating with the food industry by eliminating food-spoilage bacteria from sugar. Yeasts and molds do not survive processes now used in manufacturing sugar and sirup. If present they are the result of contamination in handling and storage.

Some trouble is encountered in the action of yeasts in candy and other confections. These yeasts have the ability to grow in sugar of very high concentration. The pressure of the carbon dioxide they produce causes the candy to burst open or foam.

Beverages of the soft-drink type constitute an important item of the Nation's food bill, and several hundred tons of energy-giving sugar and other ingredients are used each year in their manufacture.

The presence of sugar often makes a product a potential medium for the growth of bacteria, yeasts, and molds, and unless measures are taken to safeguard against their entrance, spoilage often results. Yeasts and bacteria are more often the cause of spoilage of beverages than are molds. Spoilage evidenced by cloudiness and by the accumulation of a sediment at the bottom of the bottle occurs more often in the winter than in summer, owing to slower turn-over of the stock. Continued improvements in bottle-washing methods, preparation and handling of ingredients, and automatic bottling machinery have resulted in the manufacture of beverages relatively free from spoilage.

FOOD PRESERVATION AND PROCESSING BY THE USE OF MICRO-ORGANISMS

So much emphasis is placed on the role of micro-organisms in food spoilage that the importance of their use in food preservation is often overlooked. Yet a number of large industries rely on fermentation under controlled conditions to preserve food products or to alter their character, and such methods are among the oldest employed by man for the preservation of food.

WINE AND BEER

Without doubt the first use man made of micro-organisms was in the conversion of the juice of grapes and other fruits to wine. This natural process, which prolonged the length of time a fruit product could be kept, was employed wherever fruit was available. Over 100,000,000 gallons of wine is now being produced every year in the United States.

Yeasts are naturally present on the stems and skins of grapes and on most other fruits as well. When the berries are crushed, the yeasts multiply rapidly in the juice, forming carbon dixoide and alcohol from the sugar. If the proper control is exercised over the fermentation, almost all other micro-organisms can be prevented from growing in the material. Most scum or surface-growing forms can be eliminated by sealing the product from the air and allowing the carbon dioxide formed by the yeast fermentation to sweep all of the oxygen out of the container. In making champagne, the carbon dioxide is retained in the liquid by keeping the container stoppered; a pressure of as much as 120 pounds per square inch is developed.

In order to insure a good clean fermentation, most wineries inoculate the must or juice with a pure culture of wine yeast, which gets a head start on the other micro-organisms and prevents an undesirable type of fermentation. Most wine yeasts grow well in acid solutions and at temperatures slightly below the optimum for the growth of most bacteria. Where low temperatures are not available treatment with sulfur dioxide or pasteurization of the must is often employed. Yeasts are tolerant of concentrations of sulfur dioxide that will kill most spoilage organisms.

When all of the sugar of the must has been converted to alcohol, the yeasts die for lack of food and because of the killing action of the alcohol. Light wines contain up to 14 percent of alcohol by volume, but 16 or 17 percent may be obtained by natural fermentation when the juice has a very high sugar content. By special methods of feeding the yeast an alcohol content as high as 21 percent has been attained. Wines stored in casks should be sealed from the air to prevent spoilage, and spoilage organisms in bottled wines can be killed by pasteurization.

Beer is made by a yeast fermentation of malted cereal grain extracts. The sugars are converted to carbon dioxide and alcohol as in the wine fermentation, but the percentage of alcohol produced in beer is very much lower. In the case of beer the carbon dioxide is retained in the product under considerable pressure. This not only adds to the palatability but aids in the preservation of the product. Since the acidity of the beer is relatively low there is danger of souring by the action of the lactic acid bacteria unless the proper precautions are taken. Most present-day beer is pasteurized in order to insure its keeping quality in the bottle or can.

VINEGAR

The first step in any vinegar process is the production of alcohol as in making wine or beer. Cider vinegar is produced from fermented cider, while white or distilled vinegar may be made from the alcohol distilled from fermented mashes, molasses, or other saccharine materials. After fermentation, the alcohol is converted to acetic acid by an oxidation process carried on by acetic acid bacteria. Whereas the yeast fermentation is carried out in the absence of air, the conversion of the alcohol to acetic acid can be carried out only in the presence of air. In the old barrel method the acetic acid bacteria are allowed to grow on the surface of the alcohol solution, while in the generator process the alcoholic solution is allowed to trickle down through towers filled with shavings, pumice, rattan, or other filling material. Millions of gallons of vinegar are produced each year by this use of micro-organisms in these two relatively simple processes.

BREAD AND YEAST

Leavened bread has been an article of diet for centuries. A culture of yeast is allowed to grow in a dough made of flour and water. As it grows the yeast produces carbon dioxide, which causes the dough to rise or become light. In addition, flavors are produced in the bread by the yeast or certain types of bacteria. In certain breads the growth of lactic acid bacteria is encouraged and characteristic flavors are obtained. When the bread is baked the alcohol produced by the fermentation is driven off and the micro-organisms are destroyed. Under abnormal conditions bread may become ropy, moldy, or highly pigmented by the growth of micro-organisms.

The yeast used in bread making, or bakers' yeast, is not the same as those types used in making wine or beer. It is manufactured on a large scale, and a high yield of yeast is obtained by a process that suppresses the formation of alcohol. The use of this type of yeast as a food for man and a feed for animals has built up a large industry with the sole function of growing and harvesting a yeast crop. Yeasts of this general type are the only micro-organisms that man eats as such, and they are consumed for their vitamin and mineral content.

FERMENTED FOODS

The ability of certain bacteria to form lactic acid from sugars is utilized in the preparation of so-called "fermented foods." These include pickles, sauerkraut, olives, and animal feeds on the order of silage. In these processes the sugars are converted into lactic acid. The preservation is of a twofold nature, since (1) the increased acidity exerts a selective action that inhibits the spoilage micro-organisms, and (2) most of the food for bacteria has been used up in the process of fermentation, so that there is no further material to encourage large microbial populations.

Since these lactic acid bacteria are tolerant of salt, and since salt exerts a curing action, it is employed in almost all fermented foods. Cucumbers are fermented in brines strong enough to discourage most spoilage micro-organisms, the salt and acid being soaked out before the product is used as food. This general process is also used in the production of pickled olives. In the case of sauerkraut, the salt concentration is only about 2½ percent, and the product is consumed in its final fermented form. The pleasant acid flavor of sauerkraut is the result of the bacterial activity. The process in all three cases should be carried out in the absence of air if possible in order to prevent scum formation. In 1937 the production of pickles took almost 8,000,000 bushels of cucumbers, of sauerkraut 127,000 tons of cabbage, and 25,000 tons of olives were pickled, a total farm value of over $7,800,000 for the material used in the making of these fermented foods.

The utilization of micro-organisms in the production of silage is quite similar except that very little, if any, salt is used. The process is described in Losses in Making Hay and Silage (p. 992).

MILK PRODUCTS

Micro-organisms are used extensively in the manufacture of cheese, butter, and fermented milk products. Various types of micro-organisms and various procedures are employed to produce different products and flavors. Bacteria are employed to sour milk for cheese making, and the growth of other bacteria is encouraged in pressed cheese to produce ripening. This is brought about by bacterial digestion of the curd, resulting in the development of certain flavors. Types of cheese such as Camembert, Brie, and Roquefort are produced by the action of molds, and specific flavors are produced by their growth.

Sour-cream butter is made by churning cream that has been ripened by bacterial action with a resultant production of lactic acid. The fat globules are more easily coalesced during the churning, and they take up certain desirable flavors that were produced by the bacteria during the fermentation process. Undesirable micro-organisms may produce bitter and off flavors in the cream unless proper handling methods are employed, such as pasteurization, cooling, and the use of starters.

Micro-organisms are used in the production of various sour-milk drinks, such as culture buttermilk, acidophilus and bulgaricus milks, kefir, and koumiss. The latter two are produced by the combined action of yeasts and bacteria and contain an appreciable amount of alcohol.

ENZYMES IN FOODS AND FOOD PRESERVATION

by A. K. Balls[1]

ENZYMES, which are within the food material itself and necessary to life processes, continue their chemical activity after harvesting or storage and produce decomposition. Thus micro-organisms, described in the previous article, are not the only cause of food spoilage. Here is a brief account of this enzyme activity and the methods used to prevent or minimize it.

BECAUSE agricultural production is seasonal while food consumption is steady, the storage of food in some edible form has always been one of mankind's greatest problems. Practically all natural foodstuffs except ripe seeds undergo decay unless measures are taken to prevent it. Dried fruits, pickles, preserves, cheese, and fermented drinks probably all have their origin in attempts at food preservation. Today there is an increasing tendency, due to the possibilities of cold storage, to keep foods in their natural state as long as possible. Cold storage in itself merely delays the natural processes of decay, although when the temperature is extremely low the rate of destruction is very slow. Frozen meat, if it were kept cold enough, would probably last a great many years without "going bad." Defects such as poor flavor and appearance and loss of moisture are about the worst that might be expected. It has been reported that the flesh of prehistoric animals found frozen in the Arctic was eaten by dogs without any apparent ill effect.

There are two agencies that cause decay in natural—that is, unprocessed—foods: (1) Micro-organisms, which come from contamination, and (2) enzymes, which already exist in the living tissue. The number of micro-organisms can be greatly reduced by keeping things clean, but under no circumstances is it possible to get rid of the enzymes, because they were a part of the material while it was alive. Enzymes are curious special proteins built up by the plant for the purpose of accelerating the chemical reactions that must go on if the tissue is to live. After the death of the tissue many such substances continue to function, and they cause the disintegration known as autolysis when enzymes only are present, and as decay when both enzymes and micro-organisms are present.

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If food could be stored for a very much longer period than is possible today, it would be an advantage to everybody. There do not seem to be any insuperable difficulties in the way of finding out how this can be done. Predictions are always hazardous, but it is perhaps not too rash to predict that the differences between large and small crop yields will some day be smoothed out more completely than can be done now by long-time storage.

STORAGE OF LIVE FOOD MATERIAL

Foods are stored either alive or dead. Fruit, for example, is usually stored in the living state, whereas meat is invariably stored as dead material. It is obvious that dead material may be frozen without necessarily injuring it, whereas live material cannot usually be frozen without killing it. Therefore different considerations underlie the best methods of preserving these two groups.

FRUIT

Fruit meant for storage is usually picked green and ripens during the storage period. Fruit should not be frozen nor should it be chilled too close to the freezing point. The optimum temperature for its storage varies with different fruits, but it is usually a few degrees above freezing.

The changes that fruit undergoes during live storage have been worked out very well for apples (*624*).[2] It has been found that fruit respires—that is, it takes in oxygen and gives off carbon dioxide. The production of carbon dioxide is easily measured and serves as an indicator of the vital processes taking place. As an apple ripens the amount of carbon dioxide given off increases, some of the starch changes to sugar, and some of the sugar forms carbon dioxide. At the moment of ripeness the apple gives off carbon dioxide at the highest rate; this rate then gradually decreases during a long period while the fruit grows old. The life processes as indicated by the evolution of carbon dioxide slow down in intensity and the amount of sugar present is lessened because there is no more starch to replenish it. The apple finally dies, at which time there is a short burst of biological activity followed by a fall to zero. The dead fruit then decays. The presence of molds and bacteria, of course, hastens this process, but even without them the enzymes within the cells carry on the disintegration.

Respiration is the most striking chemical process that goes on in stored fruit. Since respiration is a process of oxidation, the ripening of fruit requires a supply of oxygen. Oxidation is also observed on the exposed surfaces when some kinds of fruit are cut open. The well-known darkening of apples, pears, and the other fruits is due to this reaction. The darkening is caused by the activity of an enzyme either of the peroxidase type or of the phenol oxidase type, the difference between which is that the latter can use the oxygen of the air but the former can use only the hydrogen peroxide that is produced by the fruit during respiration. From present knowledge it seems probable that the respiration of the whole fruit, bound up as it is with the process of ripening, depends on oxidizing enzymes in which the protein of the enzyme is combined with a metal such as iron or copper.

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[2] Italic numbers in parentheses refer to Literature Cited, p. 1075.

The final result of the chemical reactions which constitute tissue oxidation, or respiration, is the same as though the food substances used (sugars in this case) were burnt. It is therefore obvious that respiration produces heat. The heat of respiration can amount to a great deal in a cargo of fruit. It is known that the rate of respiration is greatly diminished at low temperatures. Consequently, the lower the temperature, the less respiration takes place in the fruit and the less heating occurs in storage. A small increase in temperature may entail a large increase in respiration, with the result that a refrigerating machine capable of maintaining the fruit at a low temperature already reached becomes overloaded when it is necessary to cool the fruit down to that temperature. Figures showing the amount of heat evolved by respiration at different temperatures are given in table 1 (*980*). In other words, the higher the temperature, the greater the heat produced by the cargo: and the greater the heat produced the higher the temperature goes, because beyond a certain point the cooling machinery is unable to take the heat away fast enough. Once started, this vicious circle ends in the complete spoilage of the fruit. For this reason the best method of shipping fruit is to precool it before it is stored in the car or hold, thus avoiding the danger of overloading the refrigerating machinery.

TABLE 1.—*Heat evolved in a ton of fruit per day at several temperature levels*

Temperature (°F.)	Apples	Pears	Cantaloups	Temperature (°F.)	Apples	Pears	Cantaloups
	British thermal units	*British thermal units*	*British thermal units*		*British thermal units*	*British thermal units*	*British thermal units*
32	660–880	660–880	213	60	4, 400–6, 600	8, 800–13, 200	3, 938
40	1, 100–1, 760	----------	506	85	6, 600–15, 500	----------	-

There is another way of slowing down respiration and thereby lengthening the time required for ripening. It does not take the place of cooling but augments its effect. The process is based on the principle of storing fruit in the presence of carbon dioxide. Since carbon dioxide is a product of respiration, it is reasonable to suppose that a high concentration of the gas on the outside of the fruit might prevent more of the same gas from forming on the inside. Apples stored in air containing about 10 percent of carbon dioxide actually respire and ripen very slowly, and the length of time that they may be stored without damage is said to be at least twice the ordinary period (*625*).

Carbon dioxide is not the only gas given off by ripening apples, which in this respect are probably typical of most fruit. At least, two other volatile substances are produced, one of which is ethylene. The effect of ethylene on green fruit is to speed up the ripening process very markedly, so that an accumulation of ethylene in a storage space would defeat the purpose of the storage—the retardation of ripening. It is thus evident that there is need for ventilation in storage. The disadvantage of ventilation, however, is that the fruit now loses water by evaporation and may become dried out and unsightly. To prevent this, the humidity of the air is generally controlled and made as high as is possible without furthering the growth of molds. A relative humidity of about 75 or 80 percent is usually employed.

GRAIN

Ripe grain, though alive, is dormant. The germ continues to respire slowly, but the remainder of the seed behaves like dead material. On long-continued storage the proteins of soybeans and of corn have been observed to become partly denatured. This change may cause the loss of a certain amount of food value (*592*). It has been found that such changes in grain take place more slowly at low temperatures.

Flour is no longer living matter, but it is still capable of undergoing oxidative changes. There is always a large quantity of air in flour, which assures a supply of oxygen. The alterations that occur in white flour while in storage appear at first to improve its bread-making properties. White flour is therefore "aged" as a rule. The oxidation is said to cause, among other things, the partial inactivation of a protein-digesting enzyme that tends to make the dough sticky (*59*). The effect is probably similar to that of certain oxidative bleaching agents, to which improvement in baking quality is often ascribed.

STORAGE OF DEAD FOOD MATERIAL

MEAT

Meat is the best example of material stored in a nonliving state. No respiration takes place as with living material, but enzymes cause other changes. A loss of water is always to be feared in any material stored below freezing. Ordinary cloth wrappers usually suffice to decrease evaporation in stored meat. In a process recently developed a whole side of meat or a large fowl is encased in a tight-fitting rubber bag. Since meat is kept at temperatures at which biological activity is very low, the importance of ventilation is not great.

Stored meat is subject to all the natural processes of decomposition, and these are ordinarily held in check only by low temperature. Carbon dioxide, however, is an aid to preservation of meat as well as of fruit. The color unfortunately suffers, but the process is useful when meat must be shipped a long way, as from Australia (*811*). The effect of the gas is evidently to inhibit the growth of micro-organisms, but in view of the results with other products it probably inhibits enzymes as well.

When the micro-organisms are left out of the picture, meat, like all dead tissue, autolyses at ordinary temperatures, rather rapidly. The most prominent feature of the autolysis of meat is the decomposition of the protein.

Chemically, autolysis and digestion are not dissimilar, though of course in stored meat autolysis should not proceed far enough to make the similarity apparent. Autolysis is caused by a different set of catalysts, for the enzymes inherent in meat are not the same as those of the digestive tract. The Department of Agriculture has studied the changes that occur in stored beef (*518*). In particular, there is a liberation of ammonia and the production of other break-down products from protein, apparently peptides and peptones. There is also a separation of phosphate from organic compounds originally occurring in the tissue. Not only is the protein broken down during autolysis, but the fat also undergoes some decomposition, becoming more acid and sometimes rancid also. There may be no connection between these two results, but both indicate that the fat has been broken down.

EGGS

Though eggs are dead material they cannot be frozen in the shell because freezing causes the shell to burst. A storage temperature slightly above freezing is therefore necessary. Broken-out eggs may of course be frozen.

It is not often realized how rapidly an egg deteriorates just after it is laid. The nest is usually warm and not a good place for storage. The sooner the egg can be brought to a low temperature the better, and a few hours' difference may make possible many weeks more of commercial storage.

Eggs give off carbon dioxide, though they absorb little or no oxygen. This is not respiration but a form of decomposition. As with meat, however, this decomposition is inhibited by the presence of carbon dioxide outside the egg in the storage room. The result is of course an accumulation of carbon dioxide in the egg, where it inhibits the reaction by which more would be formed. The same result could be obtained by plugging up the pores of the shell and preventing the escape of the carbon dioxide formed within the egg. A coating of thick mineral oil tends to do this. According to a process tried out by the Department of Agriculture (*1115*) the eggs are dipped in oil, then the air is pumped out of them by a vacuum pump, and finally the oil is pushed into the pores of the shell by releasing the vacuum. Such eggs have been found by the candling test to grade higher after storage than untreated eggs. Just how far candling or any other method may be taken as a test of the flavor of an egg is at present hard to say. Candling probably does give some indication of flavor, but it does not seem to be very direct.

The loss of moisture by eggs in storage is serious for it causes them to lose grade. Since candling grades are based to a large extent on the size of the air cell, the prevention of evaporation is important. In order to reduce the loss of water very high humidities are often used. This is safe only if everything is clean and the ventilation is good; otherwise mold growth is favored too much. Oiling the eggs also helps to minimize evaporation of the water.

VEGETABLES

Vegetables stored in a frozen state may be considered as dead material, since no respiration takes place in them. Because of the enzymic changes to which they are subject, however, vegetables are frequently pasteurized before freezing—a process known as "blanching." This brief heating destroys some of the enzymes and prevents any rapid action in the frozen material. Enough activity remains, however, to require low storage temperatures for good results. The chemical changes in frozen vegetables are as yet little understood. Curious off flavors sometimes arise, such as the haylike flavor that occasionally develops in frozen black raspberries. To prevent loss of water in fruits and vegetables stored below freezing, waxed-paper wrappings are used to decrease evaporation.

UNITED STATES MEAT INSPECTION

by Edward C. Joss[1]

BILLIONS of pounds of meat foods are prepared annually in the United States under Federal inspection to protect consumers where they cannot protect themselves. The man in charge of this service here tells how it works and what it does.

INSPECTION of meat by the Federal Government was first authorized by Congress in 1890. It was at first designed to satisfy a demand from European countries that American meats be officially inspected before exportation. Subsequent statutes have improved the character and expanded the scope of the inspection until it is now applied to about two-thirds of the meat produced from cattle, sheep, swine, and goats in the United States and to all consignments of meat foods offered for importation. The main purposes of the present system of inspection are to search out and destroy diseased and otherwise unfit meat; to see that meat and meat products are kept clean during the stages of preparation into articles of food; to guard against the use of harmful preservatives and other deleterious substances; to cause sound and wholesome meat to be marked "Inspected and Passed" (fig. 1); and to prevent the use of false or deceptive labels and statements on meat foods offered for sale.

Severe penalties are provided for violators of the laws involved. When consideration is given, however, to the billions of pounds of meat foods prepared annually under inspection and the hundreds of thousands of consignments which yearly enter

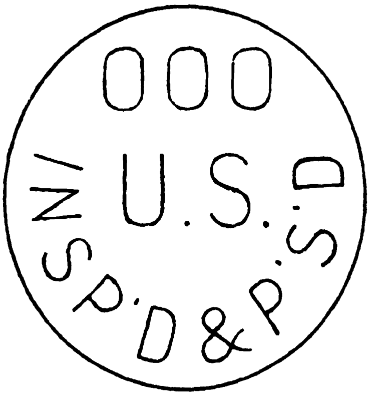

Figure 1. Mark of Federal inspection placed on inspected and passed fresh beef. Ciphers here occupy the space reserved for the official number of the establishment. A harmless purple fluid is used for stamping. Identical marks, but smaller in size, are placed on the fresh meat of calves, sheep, lambs, swine, and goats. The mark of inspection on horse meat is hexagonal in shape and green in color.

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[1] Edward C. Joss is Chief, Meat Inspection Division, Bureau of Animal Industry.

into interstate and foreign trade, there is, happily, comparatively little willful disregard of the national meat-inspection laws.

SCOPE OF INSPECTION

Inasmuch as the authority of the Federal Government to inspect domestic meat foods is limited to the supply prepared for the channels of interstate and foreign commerce, the inspection service in practical application is restricted to the slaughtering and processing establishments that prepare meat or meat food products for transportation outside the State or Territory. In other words, inspection cannot be maintained at an establishment that does not prepare a reasonable amount of meat for consumption outside the State or Territory wherein it is located. About two-thirds of the Nation's supply of beef, veal, mutton, lamb, pork, and derived products is examined and its preparation and processing watched over by veterinarians and lay inspectors of the Department of Agriculture. Primarily their job is to protect consumers of inspected meat at places where they cannot protect themselves. The other third of the domestic supply, with the exception of that part which is adequately inspected under State and municipal authority, receives little or no official attention as to its fitness for human food.

The statutes provide for the exemption from inspection of animals slaughtered by a farmer on the farm and sold or transported beyond the borders of the State or Territory and, in certain cases, of the meat of retail butchers and retail dealers.

The need for adequate inspection of meat foods is emphasized by the results obtained in the Federal meat-inspection service, which is administered by the Bureau of Animal Industry. During the 10-year period comprising the fiscal years 1930 to 1939, inclusive, there was an average annual slaughter of 72,244,260 animals at establishments where Federal inspection was maintained. In the same period the average number of carcasses condemned and destroyed annually was 230,741, and many hundred thousand parts of carcasses were likewise eliminated. Also, several thousand animals were annually found to be unfit for food purposes when submitted to veterinary examination in the pens of the establishments, and these were destroyed by official action.

The national system of inspection is well rounded out through authority to continue the examination of meat for soundness and wholesomeness as long as it remains at an establishment where inspection is maintained. These supplemental inspections in the year 1939 included 8,440,446,161 pounds of meat and meat products and resulted in the elimination of 5,338,945 pounds as unfit for food.

The cost to the Government of maintaining the Federal meat-inspection service for the fiscal year 1939 was 7.6 cents per animal inspected. On the basis of meat and meat food products, the cost was about one thirty-ninth of a cent per pound.

The statutory provision against false and deceptive labeling of meat and meat food products is emphatic, and the enforcement of this part of the law is given careful attention to prevent fraud and deception.

HOW INSPECTION IS CARRIED OUT

Before Federal inspection is granted to a slaughtering or processing plant, the plant is required to be so constructed, remodeled, equipped, and otherwise arranged as to provide the means for the maintenance of proper sanitation, and the plant must be otherwise arranged to furnish the facilities necessary for carrying on the inspection. Some of the requirements are: Ample space for cleanly operations, abundant supply of potable water, predominance of impervious floors, smooth flat-surfaced walls, means for adequate lighting and ventilating, predominance of impervious material in equipment for handling meats, hot water under adequate pressure, modern plumbing, proper sewerage, pavement with drainage connections for livestock pens, and outside premises free from objectionable conditions.

INSPECTION OF MEAT ANIMALS

Of highest importance in all good systems of meat inspection are the removal from the food supply and proper disposal of badly diseased animals and meat. These procedures require the services of veterinarians and technical assistants skilled in the work. Under the Federal system, examination begins in the pens at the inspected establishment. Here unfit animals are condemned and promptly destroyed; those less affected are specially marked and placed apart for slaughter; while those appearing normal are allowed to proceed to the slaughtering departments.

Each animal passed on ante-mortem inspection—that is, before slaughtering—is subjected to the close scrutiny of the inspectors from the time it enters the slaughtering department until the dressed carcass is conveyed into the chill rooms. While the carcass is being dressed and eviscerated the inspectors search for lesions and signs of disease. The procedure of inspection of the carcass and its vital organs varies somewhat according to the species, but in each case the veterinary examination is carried to the point where the inspector is sure that he has found and eliminated any possible bad meat. In the event disease or other sign of unfitness is present, the carcass and its organs are tagged and held in the custody of the inspector until disposition is made of them. Animals marked "suspect" and held apart on ante-mortem inspection are slaughtered separately and in a manner to allow the inspector to make an extended examination, if necessary. All condemned carcasses and other condemned material are so branded immediately and are held in the custody of the inspector until destroyed.

Carcasses that pass the post-mortem inspection are imprinted with round stamps carrying an abbreviation of the phrase "U. S. Inspected and Passed" and the number used officially to designate the establishment (fig. 1). These stamps constitute the Government's certification that the meat was derived from healthy animals and prepared under sanitary conditions.

INSPECTION OF MEAT PRODUCTS

A considerable proportion of the several billion pounds of meat produced annually under Federal meat inspection reaches the consumer as fresh meat. The remainder is ultimately transformed by curing, salting, smoking, cooking, melting, refining, canning, chopping, mixing, and stuffing into such foods as hams, bacon, corned beef, lard, cooking compounds, sausage, and many kinds of canned meat and soup. The preparation of such articles under the surveillance of the inspector requires thorough knowledge on his part of the various processes to which the meat is subjected. These duties are largely performed by technically trained lay inspectors who develop expertness in detecting unsoundness of meat. Spoilage may occur at all stages of preparation. Therefore, the product is inspected and reinspected repeatedly during the whole time it remains at the inspected establishment. Not only are the meat and derived product guarded as to soundness and cleanness, but care is taken to see that ingredients and seasonings, such as vegetables, cereal, salt, spice, and vinegar, are clean and fit for the intended use, and that no coloring matter, chemical, or other substance not officially approved is added to meat food.

It is during the processing stages that articles which contain lean pork and which, when passed on to the consumer, are customarily eaten without cooking, are required to be specially treated to destroy possible live trichinae in the meat. These are very small parasites sometimes present in pork. This safeguard to human health is accomplished by one of three official methods: (1) Heating all parts to a temperature not lower than 137° F.; (2) freezing all parts to a temperature not higher than 5° F. for not less than 20 days; or (3) curing the meat or article according to one of four special methods. Some of the products that are treated under Federal inspection to insure the destruction of trichinae, if present, are the commonly known bologna, frankfurt, and vienna-style sausages, various kinds of dry or summer sausage, cooked ham, and Italian-style smoked ham. The ordinary smoked pork such as ham, shoulder, shoulder butt, shoulder picnic, and cured loin, and all fresh pork and fresh pork sausage should be thoroughly cooked before serving, as there is no practical way of inspecting pork to give assurance that it is free from trichinae.

As a supplement to the continuous inspection conducted at the time meats are prepared, samples of curing materials, spices, added ingredients, and of meat and finished food articles are collected and sent to specially equipped regional meat laboratories for tests and examination to determine the suitability and acceptability of the articles. Careful watch is also maintained to see that water and ice supplies do not become polluted.

EXPORTS AND IMPORTS

Upon application, certificates of inspection are issued to exporters for consignments of inspected and passed meat and meat products to any foreign country. These certificates, along with the serially numbered inspection stamps which are affixed to each outside container, are this Government's guarantee that the animals from which the meat was derived were given veterinary ante-mortem and post-mortem inspection and that the meat or product is healthful and wholesome.

Foreign meat intended for sale in this country must be accompanied with proper veterinary inspection papers. An inspection is made of the shipment at the port of entry, and if necessary representative samples are sent to a laboratory for examination. That which does not conform to requirements is refused entry or is condemned and destroyed.

MISCELLANEOUS SERVICES OF MEAT INSPECTION

Cooperation is furnished to the Navy Department, Marine Corps, Coast Guard, Veterans' Administration, Bureau of Indian Affairs, and other agencies of the Government in the selection and inspection of meat and meat products for condition and conformance to the respective purchase specifications. During the year ended June 30, 1939, there were examined for these agencies 81,715,307 pounds of meat and products, with rejection of 2,048,224 pounds for not meeting contract requirements.

In 1919 Congress passed the Horse Meat Act, which was largely an export measure. It is required that horse meat be prepared and processed at establishments separate from those in which meats derived from cattle, sheep, swine, and goats are prepared and processed. Horse meat is conspicuously marked as such. It is mostly exported to Europe or used as feed for carnivorous animals in this country.

By reason of the far-flung Federal meat-inspection service and the large proportion of food animals that ultimately pass under the examination of the several hundred veterinarians and assistants inspecting these animals before and at the time of slaughter, the Bureau of Animal Industry is able to furnish aid to livestock owners and sanitary authorities in locating centers of communicable diseases. A single diseased animal in a shipment received at an inspected establishment sometimes serves, when traced back to farm or ranch, to locate a danger spot for the dissemination of animal disease. Another economic benefit of Federal meat inspection is the prevention of the spread of animal diseases and parasites through the prompt reduction into grease and tankage of condemned material at the inspected establishments, the process making it noninfectious.

SUPERVISION AND INSPECTION OF MILK

by Ernest Kelly[1]

MOST of the control over market milk and cream is in the hands of State and municipal authorities. Some communities show very little interest in efficient milk inspection, though the cost is low—10 cents a year per capita or less. Here is a brief account of the principal points covered in milk supervision and inspection.

MUCH market milk and cream (milk and cream consumed in the fluid state) is shipped interstate, but final processing and delivery to the consumer is largely local in character. For this reason most of the control over these products is exercised by State and municipal authorities. State laws may be administered by the State department of agriculture, the State dairy commissioner, or the State board of health. Municipal ordinances are enforced almost entirely by city health departments.

State laws usually are more general in character than city ordinances. They contain certain standards for fat and other milk solids, prohibit adulteration and misbranding, and usually carry essential items of sanitation. Municipal ordinances are apt to be more explicit and exacting in sanitary requirements.

In the supervision and inspection of milk and cream three main factors are involved: (1) Maintenance of nutritive value, (2) prevention of fraud, and (3) sanitation.

MAINTENANCE OF NUTRITIVE VALUE

Most States and cities have established standards for the nutritional value of milk. These have been set rather arbitrarily, and may or may not be optimum figures from a dietary standpoint. Also, the relationship required between the several components sometimes varies from the ratio normally found in milk. It is believed, however, that the consumer is more than adequately protected so far as nutritive value is concerned. There has been a decided trend in recent years toward making these standards more uniform, but the latest compilation of State laws still shows a considerable variation. For example, requirements for percentage of fat range from the highest, 3.5, to a low of 3.0; those for percentage of solids not fat, from 8.5 to 8.0; and those for percentage of total solids, from 12.5 to 11.0.

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[1] Ernest Kelly is Chief, Division of Market-Milk Investigations, Bureau of Dairy Industry.

Early laws setting fat and solids-not-fat standards were enacted largely to prevent the old practices of skimming and watering milk. Years ago these operations were fairly common, and many families received a concoction which had been diluted to stretch out the milk of a few cows to serve many customers. Fortunately scientific tests have been developed which readily detect such tampering, even to the slightest degree, and it is now extremely rare to find milk either skimmed or watered.

PREVENTION OF FRAUD

Formerly it was quite common to find false or misleading statements on the milk bottle or cap. The writer once examined a sample of milk labeled "Special Baby Milk," which contained several million bacteria per milliliter. Obviously such milk was not "special" in the usual sense, nor was it a good food for babies. Some doubtful claims are still made for certain milks, but modern supervision has held them to a minimum.

If efficient milk inspection is in force, there is little danger of the consumer's receiving adulterated or falsely advertised milk. Not only have milk-control authorities interested themselves in this question, but it has been taken up by medical and other public health bodies.

SANITATION AND INSPECTION

While it is extremely desirable to see that milk consumers are not defrauded by misleading statements or robbed of essential food values, it is even more important that their health be protected by every known sanitary precaution. For this reason, most milk inspection centers around sanitary conditions, from the cow to the consumer's doorstep.

The germs of many diseases may be carried by milk. Most of these originate from human sources, but it is well known that certain diseases of dairy cattle may be transmitted by milk to human beings. Chief among these are tuberculosis and undulant fever, the latter being the human form of brucellosis, or contagious abortion, in cattle. Cows' udders may serve as hosts to certain streptococci, such as those causing septic sore throat and scarlet fever in man. Infection from polluted water, by flies, or by direct human contact has caused outbreaks of typhoid fever.

Nearly all cities and towns of any importance have milk ordinances, which are enforced according to the local interest shown and the funds available for such purposes. It is astonishing to note the apathy in some communities regarding such a vital problem. It is often difficult to secure sufficient appropriations to obtain well-trained personnel and adequate facilities. According to the United States Public Health Service, the cost of local enforcement where its type of ordinance was in effect was about 7 cents per capita per year in cities of over 10,000 population and 9.5 cents per capita per year for cities under 10,000. It seems quite possible to secure efficient milk inspection for 10 cents per capita per year, a small sum for such protection, but even this is often not made available.

Milk inspection falls into two main divisions—sanitary inspection and examination of the product itself. The former seeks to eliminate possible causes of contamination, while the latter is a final check to make sure, so far as possible, that contamination has not occurred.

Sanitary inspection covers the whole field of production, transportation, processing, and final delivery. It starts with the cow herself and should include careful examinations and tests to exclude the possibility of such bovine diseases as tuberculosis, Bang's disease, and udder infections, which might be transmitted to man. The Federal Government, in cooperation with the States, has almost eliminated bovine tuberculosis and has done much to abate other diseases of cattle. But there should be a careful and frequent local check-up.

At the dairy farm many items need close scrutiny. Among the most important are purity of water supplies, sewage and waste disposal, health of milkers and milk handlers, cleanliness of milk utensils, prevention of contamination by flies and dirt, and prompt and efficient cooling. Cows must be comfortably housed in sanitary quarters and milk handling must be done separately and under clean conditions. Inspectors make visits to the dairy farms and evaluate the equipment and methods used. Some use a numerical score card that assigns various weights to different factors. Others use report blanks on which to record observations of existing conditions. Farms that score below a certain figure or persistently violate requirements of the milk ordinance are excluded from the market until corrections have been made.

Bacterial counts on milk are made as frequently as personnel and facilities permit. While large numbers of bacteria do not necessarily mean that milk is unwholesome, in market milk high counts indicate carelessness in production or lack of proper refrigeration and call the inspector's attention to the need of a close scrutiny of methods and operations at the dairies involved. Pathogenic, or disease-producing, bacteria may cause sickness if present in relatively small numbers. Careful and frequent medical, veterinary, and sanitary supervision is essential for all milk that is to be sold raw, and vigilance should not be relaxed even if the milk is to be pasteurized.

Most of the milk in our cities is now pasteurized. This process consists of heating the milk to a temperature high enough to kill all disease-producing bacteria that might usually be found in milk without injuring its nutritive qualities to any serious extent. It is true that vitamin C is partly destroyed by heating, but in any case milk is seldom an adequate source of this vitamin. Vitamin C can be supplied to infants in orange or tomato juice, and the normal adult diet usually does not have to be supplemented.

Milk pasteurizing and processing plants should have very close supervision, for it is here that milk receives the final treatment before it reaches the consumer. Usually such plants are inspected quite frequently. Inspectors must be sure that the pasteurization process is properly performed, especially that the required temperature is maintained for the allotted time. Care must be exercised to prevent recontamination from human sources or unclean equipment.

There should also be adequate inspection of milk that is to be manufactured into other dairy products. Much of this milk is subjected to high temperatures during the manufacturing process, but the need for sanitary supervision is not thereby eliminated. Much less attention has been paid to milk for manufacturing than to market milk, but the present trend is to tighten regulations in this field.

Many cities classify milk into various grades, such as Grade A Raw, Grade A Pasteurized, etc. Grades with similar names may vary considerably in different parts of the country. The United States Public Health Service has endeavored to unify grading systems by advocating a milk ordinance for adoption by cities. Several hundred localities have enacted this uniform legislation. When all is said and done, however, the purity of milk supplies depends to a very large extent upon the intelligence and diligence of the enforcement officials.

CARE OF MILK IN THE HOME

It is the consumer's responsibility to preserve the high quality of milk after it is delivered. As soon as possible after the milk is set on the doorstep, it should be taken in and put in a cold part of the ice box. If some time must elapse between delivery and care by the consumer, an insulated box should be provided to protect the milk from heat in summer and freezing in winter.

Milk should be put only in clean pitchers or receptacles. Milk that has stood at room temperature during a meal should not be poured back into cold, fresh milk but kept in its own container. "Keep clean and cold" is a rule that will preserve good quality and flavor in milk.

FOOD GRADES AND THE CONSUMER

by Marius Farioletti[1]

THE question of consumer grades for foodstuffs is one that has aroused widespread interest as well as many heated disputes. There are strong arguments for such grades from the economic standpoint, and there are also very real difficulties in the way of applying a widespread grading system. This article does not attempt to solve the problem, but rather to show the reader the kind of problem it is and what it involves.

THE PURPOSE of standardization is the reduction of uncertainty and waste in buying and selling. Quality grades for such merchandise as foods are a form of standardization. Devising a set of grades for a given foodstuff is an orderly and generally accepted method of accounting for significant differences in the characteristics that make up quality. Like the dollar and the ounce, a set of grades is a unit of account in exchange transactions, but it is applicable only to the commodity defined.

COMMERCIAL GRADES

The grade standards at present in use are mainly commercial grades; that is, they have been developed and promoted by traders and producers to standardize their daily (wholesale) business transactions. The consumer seldom knows what these commercial grades are. In a highly specialized economy producers and traders gain indispensable advantages from objective grades that are uniform throughout the market for the commodity. Generally accepted quality standards provide the food trades and industries with a common language by means of which the financially interested parties to a transaction will know what is being purchased, sold, and delivered without having to see it and test it themselves. Consequently, contracts can be made in clear-cut terms that minimize disputes and establish orderly bases for settling those that arise. Purchases and sales by telephone and telegraph are facilitated. Market prices are more precise in their meaning when they specifically refer to grades of a commodity. The buyer can compare the price differences between qualities and make his business decisions more intelligently. Lower grades are not shipped to distant markets at a cost for transportation that cannot be borne in competition with the top grades. Different prices for the same grade of commodity in different markets are more readily compared and uneconomic price differences eliminated by arbitrage. Markets for trading in futures are established and hedging is made possible. Farmers receive a premium for high-quality products and are thus encouraged to minimize low-quality output. Credit financing, by banks and others, is facilitated by means of warehouse receipts and the certain knowledge of the commodity characteristics involved.

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The method was developed through the process of trial and error. A food trade or industry may build up a fund of technical knowledge with respect to the quality characteristics that have been found to be marketable at different prices. When this fund of information is crystallized sufficiently to permit general agreement among traders as to the possible classification of the characteristics, the trade or industry ordinarily will agree on a definition of those quality factors that are subject to measurement within a working range of error. These defined standards of quality are not made up of exact, unchanging, or even easily measurable factors. For example, changes in methods of production or distribution, or the introduction of new varieties of the product, or even changes in the techniques of measuring the quality factors themselves, may require changes in the standards. Consequently, in different food trades or industries there are found different degrees of development and acceptability of quality standards. In the relatively new frozen-foods industry, trading is carried on largely by brands or private grades. Trading in wheat, however, is conducted on the basis of mandatory United States grades.

Individuals in trade and industry set up standards of quality and labeled them with brand names designating quality. Such brands constitute a kind of grade-labeling system. Apart from brands there are commodity exchanges that have promulgated or accepted more objective quality standards, which are mandatory for all trades on the exchange. States prescribe or authorize grade standards for certain foodstuffs. The Federal Government promulgates official and tentative grade standards for practically all foodstuffs. The tentative grades are permissive—that is, the producer or dealer may use them or not, as he wishes. Official United States grades are either mandatory or permissive. For example, wheat shipped by grade into interstate commerce must be graded according to the United States official wheat grades. Inspectors licensed by the Federal Government perform the necessary tests. All future contracts in butter must be in terms of official United States grades. For other foodstuffs, such as canned and fresh fruits and vegetables, and meats, the United States grades are permissive. Mandatory grading under United States grade standards introduces a degree of uniformity and reliability in interregional trading that would otherwise be most difficult, if not impossible, to achieve. Furthermore, national uniformity in grade standards lessens the likelihood of local, State, or regional barriers to internal trade due, for example, to nonuniformity of the standards for the same foodstuff in different States (*1123*).[2] [3]

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[2] Italic numbers in parentheses refer to Literature Cited, p. 1075.

[3] See especially the section on Grades, Standards, and Labeling in reference (*1123*).

Since trade demand is derived from consumer demand, consumer preferences play a most important part in the determination of effective commercial grades. And to the extent that commercial grades accurately reflect consumer preferences it may be said that grading for the consumer is really a problem of synchronizing consumer grades with the commercial grades. The crux of the consumer-grading or grade-labeling problem is the choice of a method for carrying forward to consumers the knowledge of how a foodstuff was graded in the trade or industry.

THE CASE FOR CONSUMER GRADES

Consumers express preferences for commodity qualities such as taste or palatability, freedom from foreign matter, maturity, size and shape, color, uniformity of size and variety, and a minimum of defects such as those due to disease or mechanical injury. Since only a limited part of a total food supply will conform to the better-quality characteristics, the top grade will command a relatively higher price than lower grades. Many consumers are willing to pay premium prices for higher quality. The grading of foods in conformity with consumer preferences would increase the probability that consumers would receive, in their everyday transactions, the higher qualities for the higher prices paid.

Grade labeling for consumers is a method for increasing consumer purchasing efficiency. It is a practical and honest way of telling consumers the quality of foodstuffs in order that they may intelligently compare the different qualities with the different prices. If buying and selling by uniform and objective grades is generally accepted as necessary to reduce uncertainty and waste at the first and middle links of the chain of exchange transactions, it is no less necessary at the final link. In general, consumers have a limited amount of money with which to satisfy their food wants. Consequently, they are under pressure to minimize waste and get the most for each dollar spent for food. In the sense that it would prevent waste of consumer purchasing power, efficient consumer purchasing would increase the real income of the Nation.

Consumer grade labeling would not mean that all consumers would purchase only the best grades. Only a relatively small percentage of a food supply will ordinarily make the top grade. There is a market for all of the several qualities of wholesome foodstuffs. But making quality grades known to the public would eliminate one important element of confusion and enable consumers to make their choices and selections more efficiently. Furthermore, if all purchases and sales are made on the basis of grades beginning with consumers and going back to the producers, the probability that producers will receive higher prices for higher quality is also increased and, in turn, production methods that increase the likelihood that the foodstuffs produced will conform to the qualities consumers prefer are encouraged.

While grade labeling for consumers is, in most instances, an effective and highly certain means for evaluating price differences, it is not foolproof and requires consumer education if it is to be used to the best advantage. Moreover, the form of consumer grade labeling should be such that it will not in itself introduce confusion. The purpose of consumer grade labeling is to provide a practical and uniform method whereby consumers can evaluate quality differences without regard to private brand or price. This would increase the chance that quality and price would go together. Consequently, consumer grade labeling should be independent of private grades or brands, and should transcend them.

Consumers who desire high quality should not need to resort to the uncertain and wasteful method of paying high prices in the hope of getting it. They have the right to know what quality they are buying. Consumers are in fact demanding truthful, concise statements of grades, as simple as A, B, C, or 1, 2, 3. Simple A, B, C grade labeling may be complemented by such additional descriptive information as may be appropriate to the product in canned foodstuffs, for example, count of pieces in the case of peaches, sieve size in the case of peas (fig. 1), strength of sirup in the case of fruit. Simplicity in grade labeling includes uniformity of grade names. If U. S. No. 1 designates the highest quality for some fruits and vegetables, whereas for other fruits and vegetables there are grades above U. S. No. 1, such as U. S. Fancy and U. S. Extra Fancy, consumer confusion is to be expected and the effectiveness of grade labeling will be lessened.

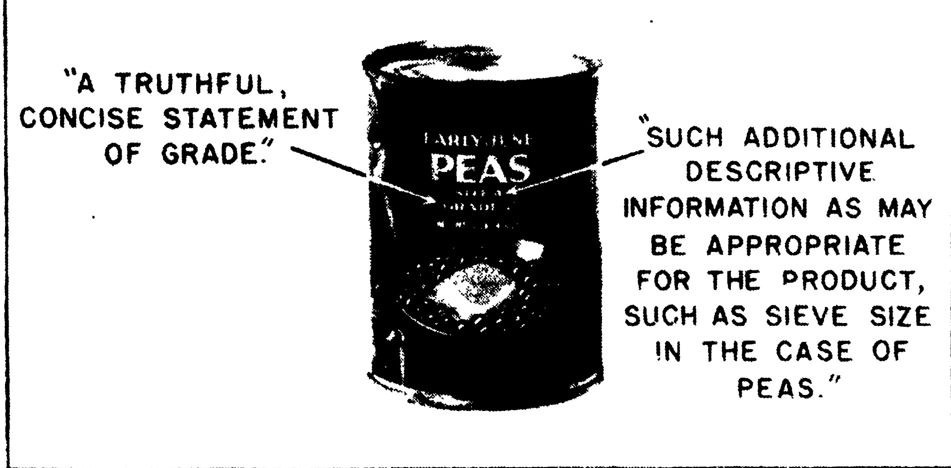
"A TRUTHFUL, CONCISE STATEMENT OF GRADE."
PEAS
"SUCH ADDITIONAL DESCRIPTIVE INFORMATION AS MAY BE APPROPRIATE FOR THE PRODUCT, SUCH AS SIEVE SIZE IN THE CASE OF PEAS."

Figure 1.—Method of labeling to designate grade as recommended by the Bureau of Agricultural Economics.

The extent to which grade labeling for consumers can be synchronized with existing commercial grade standards varies with individual foodstuffs according to the method of handling or processing; the customary point of grading; the degree of perishability and the interval between the time of grading and the consumer's purchase; and finally the technical ability to translate consumer preferences into defined quality differences capable of objective measurement with reasonable accuracy and at insignificant cost per unit of product.

Research in consumer preferences may discover that for some foodstuffs, at least, the grade standards used in a trade or industry are not so closely related to these preferences as they might be for optimum consumer satisfaction. If such discoveries are made, a reappraisal of the grade standards will be in order. Until then, however, it may be assumed that there is a real and significant relationship between a set of grade standards used in the trade and consumer preferences. Consequently, if it is technically possible to measure quality differences with a degree of objectivity acceptable to the trade, in all probability this objectivity can be transmitted to consumer grade labels.

BRAND NAMES

It is generally agreed that canned foodstuffs need to be grade labeled for consumers. The containers are opaque, and consumers have no opportunity to determine quality until after the purchases have been made. In this case, the problems of grade labeling for consumers are not technical but economic. The canned foods are graded for commercial purposes, and the grades could be made known to consumers easily. The canned foods purchased by consumers are for all practical purposes of the same grade as when they were graded at the cannery.

However, the practice of selling to consumers by brand or private grades is the rule. The owners of these brand names have a vested interest in the names that is competitively valuable to them. In most food trades or industries individuals have little control over market conditions. Advertising and other sales efforts are a form of control to which an individual can turn and expect results. Consequently, traders and processors brand their commodities and through advertising and other sales efforts try to associate in the minds of consumers the desirable quality characteristics of a commodity with a particular brand. In this way the individual can expect partly to protect himself from unknown changes in market conditions over which he has no control and which may be detrimental to his business interests. His costs of processing and distributing the brand of commodity may be appreciably increased, yet his competitive position in the industry may be bettered if the sales efforts have developed a relatively steady demand for his brand.

It is easy to understand the unwillingness of the trade to accept a uniform and simple A, B, C grade-labeling system in preference to private brand labels. The owners of brand names believe that they will lose whatever advantage they derive from the names even though consumers definitely gain. Branding is not a simple and uniform grade-labeling system. The large number of brands and the multiplicity of descriptive labels, when there is a description, confuse consumers. They cannot evaluate the different prices of two different brands of a foodstuff without an accurate knowledge of the comparative qualities of the foods. Consumers should have no objection to brand labeling if it is accompanied by a statement as to quality and such additional descriptive information as may be appropriate to the foodstuff. Some progressive canners and merchandisers are already labeling canned foods with simple statements of quality such as A, B, and C.

MEAT, BUTTER, EGGS, FRUITS, AND VEGETABLES

For some foods, such as meats, butter, and eggs, grade labeling for the consumer involves a reclassification of commercial grades. The quality gradations in the trade are finer than is necessary or significant for consumers. Small price differences that are not significant to consumers are often of importance to traders, such as waste and cut-out value in carcasses. As a result there are many more commercial grades than are necessary for consumer differentiation. These finer gradations which may be called trade preferences, are in addition to consumer preferences, but nevertheless closely related to them. Obviously, cut-out value is important to traders simply because consumers purchase meat by specific cuts, the yields of which vary by certain carcass characteristics.

For meats, consumer grade labeling is almost entirely permissive. The one exception is the ordinance of Seattle, Wash., which requires that only graded meats be sold at retail. These retail grades designate the same qualities as commercial grades, but the gradations are not so fine. Some retail outlets in various cities voluntarily sell fresh meats by United States official grades (fig. 2). For such meats as hams and bacon, packer brands or grades are the rule. Poultry is sometimes voluntarily grade labeled for consumers.

For butter the quality score standards are the same for consumers as for the trade, though they are not always understood by consumers. Butter is ordinarily sold to consumers by brand. However, in California all butter sold must be grade labeled, irrespective of brand, as first, second, and third quality, each quality representing a range of score.

There are official United States retail grades for eggs which are differentiated from the trade grades primarily by lower tolerance for off-grade characteristics. These retail grades are permissive. However, New York requires all eggs sold at retail to be grade labeled. The grades conform closely to the Federal standards. Oregon also requires the grade labeling of eggs.

Grade labeling of fresh fruits and vegetables for consumers presents certain problems. Such foodstuffs are perishable, and because of the time and distance involved before reaching the retail markets, they would often have to be regraded if the grade labels were to represent accurately the quality received. In fact, even though shippers, dealers, and wholesalers ordinarily purchase fresh fruits and vegetables by grade, retailers and consumers ordinarily purchase by personal inspection. Furthermore, fresh fruits and vegetables are not generally sold to the consumer in the package originally graded, but from the bins or counters of the retailers. This adds to the difficulty of maintaining the grade-label identity through to the consumers. Consumer packaging and regrading might add significantly to the cost of marketing, and it is a question whether the advantages of grade labeling are worth the increased costs in such cases. However, even though consumers can purchase by inspection, they cannot always identify quality characteristics with a high degree of certainty. All is not gold that glitters, and consumers do overemphasize appearance, though it is only one determinant of quality and may not be closely related to other quality factors. Purchasing fruits and vegetables by telephone would be facilitated if consumers could purchase by grade, and the housewife with limited shopping time would benefit. For some fruits and vegetables, such as potatoes, the grade-labeled consumer package is proving to be economically feasible for the top grade.

Figure 2.—Some retail stores voluntarily sell fresh meats graded by the United States Government.

CONSUMER LABELS OTHER THAN GRADING

Inspection services such as those performed by the United States meat inspectors are not equivalent to grading. They are for the purpose of maintaining the health of the community by assuring consumers clean and wholesome foodstuffs. Grades, on the other hand, imply consumer evaluations of qualities that apparently give different degrees of satisfaction. The determination of whether or not a foodstuff is clean and wholesome is independent of what its quality may be. Consequently, the fact that a foodstuff has been inspected and passed in itself carries no information to the consumer as to its probable grade.

Under the Federal Food, Drug, and Cosmetic Act of 1938, standards of identity for foods (excepting dried fruits and fresh or dried vegetables) are promulgated by the Secretary of Agriculture. That is, after public hearings for industry and consumers, determinations are made of such problems as how much fruit and how much sugar jam should contain to merit the name "jam." Minimum standards of quality are also determined. These minimum standards are a kind of mandatory consumer grade-labeling system. However, it is a very incomplete grade-labeling system because the grade-labeling mandate applies to substandard quality only. That is, the Food and Drug Administration really sets up two grades, a minimum standard of quality that can normally be met by industry, and a substandard quality that is below the minimum standard. If a foodstuff meets the minimum standard required, or surpasses it, no label need be attached declaring the fact. If it falls below the minimum it must be labeled "substandard." The foodstuff determined to be substandard is nevertheless a wholesome food, generally as nutritious as the standard foods of higher quality.

WHAT THE MODERN HOMEMAKER NEEDS TO KNOW

by Miriam Birdseye

THE author of this article contrasts a country Christmas dinner in 1680 with a city Christmas dinner today to show what has happened to food production and processing in our modern industrialized money economy. She points out that homemakers must develop a new kind of skill in food management, but that the farm home has much to gain by adapting some of the older ways to modern needs.

CHANGES IN 250 YEARS

IN THE American colonies 250 years ago almost every step in the preparation and processing of food, from the raw material to the table, was performed in the home, much of it by the housewife or under her direction. This meant that she had first-hand knowledge of the ingredients and the quality of practically every product the family ate. Today, on the other hand, almost every food product that is susceptible of primary or secondary processing [2] is available for sale in commercially prepared form for those who have the money and the desire to buy it.

Farm families constitute the only appreciable group in our population which still finds it possible and to a large extent advantageous to perform for itself the bulk of the food-processing operations that industry performs for a large part of the wage-earning city population, and that the middleman, the wholesaler, and the retailer distribute.

To visualize the changes brought about by industrialization of food processing, let us contrast the preparation of a holiday meal in a colonial homestead and in a typical modern apartment without a maid, where, by virtue of the fact that the homemaker holds a job, the family

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[2] The term "primary processing" as used in this article refers to the conversion of raw products into usable and durable form, as in making flours and breakfast cereals from grain, sirup and cornstarch from corn, and molasses from sugarcane or sorgo, or in canning vegetables and curing meat. Secondary processings involve the combination of several raw and primary-processed products into a product wholly or partly ready for immediate use. Typical examples of secondary-processed foods are baked goods, ready-made mixes, soups, salad dressings, and toppings. It is a question whether cold storage in wholesale quantities without preliminary treatment, as in the case of eggs, meat, fowl, and fruit, or the holding of other products like sweetpotatoes at higher temperatures should be classed as primary or preliminary processing. Much of the industrialization of food handling, of course, begins at this point.

of two has a reasonably good income but comparatively little time outside of office hours for homemaking activities.

Present-day Americans are amazed by well-authenticated accounts of foreigners who visited the Colonies in the early 1700's and actually saw wild turkeys weighing 30, 40, and even 60 pounds and selling for 25 cents apiece, oysters 12 inches long, 5-foot Chesapeake Bay lobsters, flights of pigeons that broke down whole branches under their weight, a wealth of waterfowl and fishes, deer and bear that might be had for the taking, and stupendous combs of wild honey stored in bee trees. Small wonder that after the first few years of privation pioneers from the Old World, with reasonable industry, could feast on occasion.

CHRISTMAS DINNER, SEVENTEENTH CENTURY STYLE

Let us attend a not-too-elaborate Christmas dinner on a Maryland tidewater plantation about 1680. The menu includes oysters on the half shell, turtle soup, ham, venison, turkey and ducks, potatoes, sweetpotatoes, and other vegetables, jellies, conserves, and pickles, pumpion (pumpkin), mincemeat, and apple pies, custards, syllabubs, and other desserts, coffee, and sweetmeats. Good cheer is provided by cider and "diwers wines and spirits."

Such a feast was literally the climax of a year's planning, planting, and preserving, with several days given up to intensive preparations at the last.

The oysters, of course, could be had for the gathering. The terrapin was caught locally and simmered in the pot hanging from the lugpole of green wood that spanned the huge fireplace, or from its successor, the iron crane. The hams, cut from choice home-raised porkers, were sugar-cured, hickory-smoked, and aged for months before they were ready to boil in home-pressed cider. The meats and game were roasted on spits in tin reflector "ovens" before the fire, with constant turning and basting, and the fire itself must be constantly replenished and burned to glowing coals. The herbs used for seasoning, cut last summer at their prime, were hung from the rafters to dry, and carefully stored. The vegetables were planted, gathered, and stored, and wild and cultivated fruits garnered in their season and made into sparkling jellies, plain or brandied preserves, or candied sweetmeats. Relays of hot, flaky biscuits will supplement wheaten loaves baked in the chimney oven, first heated with its special fire of twigs and small wood, and then brushed clean. The veritable fleet of "pyes" sweetened with honey or molasses has been made well ahead and set away in the north pantry. But before either the bread or pastry could be made, the grain had to be taken to the mill and ground into flour, the lard tried out with sprigs of rosemary and stored in wooden tubs, the cooking butter churned and packed down with salt or brine in big stone crocks. Of course, fresh churnings have been made for table use on the festive day.

Wines of dandelion, blackberry, elderberry, plums, and grapes were made in season and stored in cool cobwebbed cellars months or even years ago, but the cider has been prepared just far enough ahead to give it a bead and a tang. The choicer wines, brandies, and rum were imported, of course, from the Old World or from the West Indies. From the West Indies, too, come gleaming 10-pound cones of pure white sugar, kept under lock and key in a metal-lined casket. It has been the sweet duty of one of the young ladies to cut with a pair of dainty sugar clippers from such a cone a store of beautifully proportioned sugar cubes, sufficient to serve with that delicious new-fangled drink, the after-dinner coffee—imported green, and freshly roasted and ground at home.

Now at last the table, with its gleaming damask and "best chany" imported from France or England, is ready. The mistress and her daughters, having planned or supervised the preparations from first to last, withdraw to rest and make their festive toilettes, against the coming of kinfolk and guests. For though a holiday dinner requires all this work, it is an event in the lives of servants as well as masters, and the more guests the merrier.

When the meal is over comes the aftermath of clearing up. The soft soap made last spring from the winter's discarded fat combined with lye leached from hardwood ashes in a wooden trough may be hard on the hands, and the dishwater has to be carried from the creek or the well and slowly heated in huge kettles, but what of that? Who stops to think that the firewood was cut last winter in the wood lot, dragged home on a sledge, and chopped to the proper size; or that if the fire goes out, it must be rekindled with flint, steel, and tinder, or with embers borrowed from some other hearth? If the wind scatters ashes over the floor, they can be swept up with the birch broom or the turkey-wing fan. Many hands make light work, and in a new country there are few occasions to compete in interest with a big family gathering.

CHRISTMAS DINNER, MODERN

Now to look in on the assembling of an apartment-house feast, modern style. In the 6- by 8-foot kitchen there is not much room to store things away or to lay out dishes, and it costs a lot for the homemaker to stay away from the office. What with the desire to keep slender and the need for hurry-up meals at both ends of the business day, her hand just is not "in" for preparing rich, time-consuming dishes. This household has no children, no maiden aunts, no servants to call on except the woman hired by the hour to serve and clean up. Plans must be laid well ahead, of course, but the actual work consists mostly of buying and assembling.

The cocktail, ready mixed or as "makings," comes from the drug store in the basement of the huge apartment building, and from grocery or delicatessen come ingredients for the hors d'oeuvres to go with it. The oysters and clear soup are easy—the radio has been pleading for weeks that you "buy that soup *today!*" Wafers? From a box, of course.

Just smell that turkey roasting! The housewife-business woman bought it quick-frozen in a bag, thawed it in her mechanical refrigerator, and stuffed it with day-old baker's bread, Minnesota butter, Utah celery, local parsley, and poultry seasoning from a freshly purchased tin. Cranberry sauce comes in a can, or even in dried flakes. Quick-frozen lima beans and spinach need only to be dumped from their cartons into boiling salted water and will be ready in less than 10 minutes. There is no substitute for the personal touch to the sweetpotatoes, however. Boiled and sliced, they are baked with a glaze of butter, brown sugar, and a spoonful of bottled honey. The salad is put together by hand, crisp from the refrigerator, and colorful; and French or mayonnaise dressing from the store can be given an individual touch from the jar of dried salad herbs or a silvered wedge of Roquefort cheese. If the hostess mixes her own dressing, the olive oil may come from California, the vinegar from the Shenandoah Valley, the lemons and the pot of chives from Florida. Cloves of garlic, grown in the Connecticut Valley, were slipped into their cellophane envelope in Philadelphia. Along with Jersey endive, Texas lettuce, and greenhouse cucumbers and tomatoes, all are waiting in the basement grocery store.

The pies are made from canned pumpkin, canned mincemeat with trimmings, and pie-crust mix, and served with assorted cheese segments in tinfoil. The hostess preferred them finally, after considering a plum pudding, heated in the can and served piping hot with a ready-prepared sauce, and ice cream, which the dairy delivers packed with "dry ice."

Raisins and salted nuts come in cellophane wrappings or glass containers. And last, of course, the coffee, ground a few days ago for her favorite kind of pot and vacuum-packed or sealed and dated, to be served with tiny sugar lumps and multicolored mints from a box.

Even with so much labor paid for in the form of processed goods, there's plenty of work to assembling and clearing away a holiday meal for six. But when the dishes are scraped and stacked, washing is easy with scalding water from the swinging faucet and plenty of soap flakes. Rinsed and placed in the dish drainer, the china dries itself. The waxed linoleum is brushed up, a spot or two wiped off, and the kitchen floor is in shining order.

NEW SKILLS NEEDED BY HOMEMAKERS

These changes have come about through many causes, chiefly industrialization and the shift to a money economy. This means that instead of producing and processing at home much of what they need, the town and city populations produce no raw material, but instead market their time, labor, and skills for wages or salaries, which they in turn use to buy goods provided and services rendered by others. The processing of food has been transferred from the household to larger and larger industries, and these industries aim for survival through greater volume of production and wider distribution.

Home consumers have benefited by the industrialization of food processes, but they have lost by it too. The family as a unit loses through the reduction of the contribution that the housewife and the children previously made to the home by their labor, which added to the real income of the family. Shifting of work to the processing plants has minimized the home as a center of training for technical skills and postponed the time when a child feels himself a useful member of the household. The early training in the skills that kept the family going and the consequent association of children and parents were very real influences in developing character and personality.

Processing for profit is subject to the temptations that beset any business. The unscrupulous resort to adulterations and misrepresentations that may enhance profits at least temporarily. The chief of the bureau of food and drugs of a State department of health recently listed among the duties of his staff the inspection of milk for cleanliness, freedom from adulteration, and proper pasteurization; ice cream for butterfat content and sanitation; butter for fat content; oil for freedom from adulteration; chopped meat for freshness, adulteration, and preservatives; canning factories for sanitary condition of foods, machinery, and workers; fruit for poisonous spray residues beyond the legal tolerance; shellfish, and the water in which they grow, for pollutions injurious to public health.

Processing as now practiced also adds a whole series of material and labor costs to the original price of the raw material. Some of this increase is necessary and some is not. Thus the percentage of the family budget required for food may increase to a point where it is out of proportion to the other items.

Placing food production and processing within the money economy requires that consumers develop an understanding of a different economy field and a new series of skills to take the place of the old. If enough money and understanding are available, consumers have a better opportunity to obtain a superior year-round diet. But the very poor, especially if they lack understanding, find the cost of a good diet prohibitive.

What do modern homemakers need to understand if they are to profit the most and suffer the least from the present industrialized stage of food distribution and food processing? Since homemakers do most of the consumer food buying, let us set down the minimum essentials of the guidance they need.

As a background, they need to know the proportion of the family income that may safely or wisely be allotted to food, and the quality of diet the allotted sum will provide if intelligently expended. This necessitates at the very least a working knowledge of the food groups that must be included in the daily diet, the representatives of each group that are cheap or dear in terms of food value and price, the relative contributions of refined and nonrefined foods in the same group, and the value in the diet of the "protective" foods. They must understand the rudiments of body requirements for growth, maintenance, and muscular work, and the main contributions the various food groups make to those needs. The foregoing information helps them to keep food expenditures within bounds and shows how important it is to secure health essentials first.

Homemakers also need to form the habit of planning meals several days ahead and of checking them by a daily food guide to insure that they follow the meal pattern or the diet plan selected.

A food list for a week or other convenient period, which tells how much of each particular food group must be used to build up the selected diet, is the next aid needed; and since there is a wide selection in most of these groups, homemakers must also make a market list based on the food list and on considerations of food values and current prices. For the city consumer, Thursday or Friday evening is a good time to make plans for the week, for the newspapers then carry information on week-end specials and prices.

This minimum background could advantageously be greatly expanded, but it prepares the housewife for the actual selection of raw and processed foods from the various sources of supply.

In these days food guides and food lists are easily obtained in Government publications and popular texts and through free classes or groups conducted by home economics teachers or home economics extension workers.

It will help the housewife greatly if she knows and takes advantage of customary seasonal price fluctuations for the various commodities. The effects of good and poor growing seasons and of carry-overs from last season's supply are also reflected in prices, as well as the long swings in the supply of animal foods known as cycles.

The homemaker should make it a habit to study at the store the label of any product she proposes to buy. The law requires that this label state the weight of contents. Comparing weights and prices of the same article in containers of different sizes guides her in selecting the best value for her own conditions. She will need to know also what brands and commercial grades give the most satisfaction for the money expended and the use she wishes to make of them. She is fortunate if in her neighborhood she can find canned goods not only commercially graded for quality but also labeled with Government quality grades. Such quality-grade labeling tells her at a glance the characteristics of the contents and their suitability for her immediate purpose and for her budget.

What has already been said of the need for supervision of the sanitation and the quality of food products moving in local, State, and interstate channels indicates that consumers need to understand, stand back of, and when necessary promote appropriate laws and regulations for their own protection.

All this will develop the homemaker's discrimination in studying claims made by food distributors, whether through magazine advertisements, the radio, or the press. Thus she will be less likely to be swept off her feet and away from her buying plan by glittering promises and beguiling offers. In fact, she will develop that "stop, look, and question" attitude which is the first requirement of the shrewd buyer

HOME PRODUCTION AND PROCESSING ON THE FARM

The farmer, drawing the major part of his gross cash income from the raw materials produced on the land he cultivates, is like the merchant in that the expenses of his business must be subtracted from gross income to determine net income available for family living. In this respect the farmer differs from the wage earner, whose gross and net income are almost identical.

The merchant's family has an advantage in being able to obtain at wholesale prices such items as the business and business acquaintances handle. The farm family is benefited through its so-called farm privileges—the cash-sparing housing and fuel that come with the farm, plus such amounts of the cash crops as the family makes use of. In addition, it is at an advantage when available land and labor can be employed in raising and processing additional foods needed for the family table without correspondingly reducing cash profits.

Considerations of climate, soil, labor, skill, inclination, and the profits that may conservatively be anticipated year in and year out from land and labor invested in cash crops, or from labor performed by family members off the farm, help a farm family decide for each essential food whether it is better economy to raise and home-process it or to buy it from retail stores or from neighbors. These are decisions which the family should reconsider yearly, keeping in mind that farm people often go without the protective foods that they do not raise. Strangely enough, some families consider it economy to sell, at farm prices, protective foods that they produce, like milk and eggs, which they really need for proper nutrition, in order to buy at retail other foods that contribute far less to the diet.

Were it not for the advantages derived through farm privilege and the opportunity to draw upon unpaid family labor as needed to process the raw foods the farm provides, the cash incomes of farmers as a group would be inadequate to maintain a desirable standard of living. The Bureau of Home Economics includes, in gross and net farm-income figures, not only the cash income but the money value of the housing and fuel the farm provides and of the food the family raises and actually consumes.

The availability of raw materials and family labor, of storage space, work space, and equipment of a sort, combine with small cash incomes and the inconvenience of buying at a distant food center to make the farm household a link between the self-contained production and consumption cycle of the early colonial homestead, which fed and clothed the family with almost no exchange of cash, and the city family where all or most members of working age market their services for cash and pay out cash in turn for the necessities of living.

When the farm family raises its own raw foods, processes and stores them at home, and finally prepares them for the family table, it short-circuits price increments arising from such operations as farm marketing, manufacturing, and wholesale and retail distribution, with the contributory costs of transportation, storage, advertising, and financing.

A sizable portion of our population earns its livelihood or invests its savings in the transportation of foods by rail, steamship, or motortruck, in storage under diverse conditions, in advertising through various channels, and in financing the whole series of movements between farm producer and ultimate consumer. The farm family that produces much of its food supply at home and thus uses raw materials minus these price increments usually has a much more generous and well-balanced diet than the family that uses its land and labor for cash crops, subject to all the hazards of production and price fluctuation, and then buys most of itsf ood out of net cash income.

Costs of farm production and marketing are heavy, and climate and price fluctuations take their toll of farm profits. This is shown by the recent consumer purchases study of the Bureau of Home Economics. In 1935–36 net family income was compared with gross farm income in selected counties in Vermont, Pennsylvania, Washington, and southern California. Net income was never more than about 50 percent of gross farm income. As gross farm income increased, net income increased also, but never at as rapid a rate.

Purchased at retail, an adequate, well-balanced food supply costs between $100 and $165 a person a year. The farm family in the median- or lower-income brackets simply cannot get ahead, and indeed is fortunate if it does not fall behind, when the amount available for family living must defray a major part of the food cost. The alternative is a diet below a desirable level.

Canning and preserving, butchering, curing meat, making sausages and other meat products, butter, soft or hard cheese, bread, and pastry, and in certain areas grinding cereals and meals from home-grown grain are still familiar processes on farms, where family labor shifts rapidly from one operation to another as the week or the season progresses.

That home processing actually does spare cash has been shown again and again by records kept in more or less detail. In 1937, a Kansas housewife, following up a lesson on home bread making, reported: "I can easily save half the cost of our weekly bread supply by making my bread instead of buying it." A bulletin of the Vermont Agricultural Experiment Station (*831*)[3] recently stated that for a family of five or six persons about $24 a year could be saved by making bread instead of purchasing it. To the salaried worker this saving may seem negligible; but added to a farm-family clothing budget of, say, $100 a year for three persons, it offers definite possibilities.

An enthusiast for home processing of food (*136*) quotes figures based on time and cost studies of actual operations in a well-equipped home kitchen, which indicate that home processing results in sufficient savings to compensate the housewife for her time at a price considerably above the average factory or clerical wage. She estimates that out of a possible total of $101 spent yearly for baked goods by the average American city family of three or four persons with a cash income of $2,100, $45 could be saved yearly, with a time expenditure of approximately 2 hours a week. The return on the housewife's time would thus average 43 cents an hour—varying from 32 cents for making whole-wheat crackers to $1.28 for baking muffins and chocolate nut brownies. She contends that these savings would justify the ownership of a modern electric or gas range with temperature controls, an electric mixer, and $200 to $300 worth of equipment, the investment totaling between $300 and $500. Needless to say, the farm families who most need to save could not afford many of these labor-saving devices, but would contribute more hours of labor.

The farm kitchen has a long history as a processing plant, however. Early American kitchens were a combination of cooking center, dining room, living room, and factory for the periodic or seasonal processing of foods and often for spinning, weaving, and garment making. Pioneer kitchens often served as bedrooms at night. Since the kitchen was the only really warm room in cold weather, it was necessarily the family gathering place and the domestic workshop.

The farm kitchen is still a real food-processing plant. The volume and variety of work turned out in it demand good ventilation, good lighting, and efficient arrangement. The cash savings brought about by home processing justify a reasonable investment in efficient equipment for cooking, refrigeration, storage, washing up, and cleaning; and up-to-date canning equipment is a necessity.

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[3] Italic numbers in parentheses refer to Literature Cited, p. 1075.

BETTER NUTRITION AS A NATIONAL GOAL

RAISING the nutritional level of any large proportion of the people of the United States is far more than an individual problem. It would involve a great deal of education; increased purchasing power, or lower food distribution costs, or both; and in the long run—at least if a really high nutritional level is to be attained—considerable increases in the production of the so-called protective foods. These are not problems that can be solved overnight. The first step, in fact, is to find out what the problems are; and this article explores them from several angles.

THE PROBLEM

by Hazel K. Stiebeling[1]

IF OUR present knowledge of foods and nutrition were generally applied, it would revolutionize dietary habits and have far-reaching implications for national health and for agriculture.

Diets that can be classed as good, nutritionally speaking, include more of the protective foods—milk, leafy green-colored vegetables, and vitamin C-rich fruits—than do usual diets. According to preliminary estimates based on all data now available, the percentage increases of these foods needed to raise present levels of family consumption to the rather generous level of freely chosen diets that can be rated good nutritionally are approximately as follows:

	Percent increase
Milk	20
Butter	15
Tomatoes, citrus fruit	70
Leafy, green, and yellow vegetables	100
Eggs	35

Even these freely chosen "good" diets are far from optimal. According to the best estimates of internationally recognized experts in this field, we should do well to double our consumption of dairy products.

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Even if the consumption of these products were increased only among those families that are now consuming less than the quantities specified in a plan for an economical fair diet (see Planning for Good Nutrition, p. 333), and then only to the level specified in that plan, much more food would be consumed than at present. The percentages are approximately as follows:

	Percent increase
Milk	10
Butter	10
Tomatoes, citrus fruit	10
Leafy, green, and yellow vegetables	80

And if all nonrelief families chose to select their food in accordance with plans for satisfactory diets suited to their incomes (see Planning for Good Nutrition, pp. 332–340), the increases called for (assuming the 1935–36 distribution of families by income) would amount to:

	Percent increase
Milk	16
Butter	26
Tomatoes, citrus fruit	8
Leafy, green, and yellow vegetables	80

These figures indicate the proportionate deficiencies in the consumption of protective foods in this country. The consumption of at least 10 to 20 percent more milk, 10 to 25 percent more butter, 25 to 70 percent more tomatoes and citrus fruit, and about twice as much of leafy, green, and yellow vegetables would be advantageous to the nutrition of our population.

The deficit is found chiefly, though not exclusively, among low-income groups. These include families on relief and the many nonrelief families whose incomes are so low in comparison with the number of family members requiring support that their levels of living are just as low as and often lower than those of relief clients.

From the standpoint of health better diets could mean smaller outlays for illness, less loss of working time, greater physical efficiency, and longer, more productive life. For agriculture, better diets would mean increased production of fruits, succulent vegetables, butter, and milk, and hence more cows and the production of more feed. With increased longevity, people would need all kinds of nutritious foods over a greater number of years.

Farm families that can produce a large share of their own protective foods enjoy certain advantages over their village and city neighbors. With favorable growing conditions and a willingness to invest the necessary land and energy in the project, farm families, even at comparatively low economic levels, can have an abundant and varied food supply the year around. But to make sure that the food supply will be patterned according to the family's nutritional needs, takes more capital and more planning ahead than many yet manage.

In cities and villages one family out of every seven not on relief is handicapped as consumers of food by lack of purchasing power. At current retail prices, their food expenditures do not cover the cost of even an economical diet providing average nutritive requirements, and it is scarcely to be expected that they use the money now spent for food most advantageously for good nutrition.

Many families spend enough to buy adequate diets, but some have too little knowledge of food values or appreciation of the importance of good nutrition to select diets as good nutritionally as low-cost adequate diets could be. Such families need the kind of information that will arouse their interest and help them get better value for their food money—better not only in weight and market quality, but in the "hidden" nutritional values.

PURCHASING POWER AND THE DIET

One important factor determining quality of diet is the level of expenditure for food. With food prices and buying habits as they were in 1934–37 (*1104*), in most parts of the country families of employed workers in cities spending $1.25 or less a person a week for food had poor diets. Of those affording $2.50 to $3 a person a week, almost half were found to have fair or good diets, the others, diets considered to be in need of improvement in one or more nutrients. At a still higher level of expenditure—about $4 a person a week for food—about three-fourths of the families had fair or good diets and about one-fourth poor. High purchasing power contributes to improvement in diets.

Purchasing power may be increased through increased incomes, lower food prices, or both. Without increasing purchasing power, better diets might be obtained by spending a larger proportion of present income for food.

The number of persons in a family as well as the size of income is important in determining how much money can be spent for food. Of course a given income does not go so far in covering the needs of a large family as of a small one. As in the case of a reduction of income the support of a larger family on a given income generally leads to an increase in the proportion of total expenditures devoted to food, but at the same time there is usually a decrease in the absolute amount spent for the food of each person.

Table 1 shows which of the four diet plans described in the article Planning for Good Nutrition (p. 321), could be obtained for the sums now spent for food by city and village families differing in size and income. The estimates of the costs of the diets were obtained by pricing the food groups listed in the diet plans according to regional food choices and retail prices.

TABLE 1.—*Diets purchasable (1938 prices) for sums generally allotted to food by families differing in size and income*

Annual income class	Diets purchasable by a family of—			
	2 persons[1]	3 or 4 persons[2]	3 to 5 persons[3]	5 to 8 persons[4]
$500–$999	Low cost or moderate cost good diet.	Economical fair diet or low-cost good diet.	Economical fair diet or low-cost good diet.	Poor or economical fair diet.
$1,000–$1,499	Moderate-cost or expensive good diet.	Low-cost or moderate-cost good diet.	do	Economical fair or low-cost good diet.
$1,500–$1,999	do	do	Low-cost or moderate-cost good diet.	Do.
$2,000–$2,999	do	Moderate-cost or expensive good diet.	do	Low-cost or moderate-cost good diet.
$3,000–$4,999	do	do	Moderate-cost or expensive good diet.	Do.

[1] 2 adults.
[2] 2 adults and 1 or 2 children under 16 years of age.
[3] 2 adults, 1 person 16 years of age or over, and 0 to 3 other persons.
[4] 2 adults, 1 child under 16 years of age, and 2 to 5 other persons.

The proportion of income now spent for food is low in the United States as compared with many other countries. In 1935–36 food expenditures in this country took more than 40 percent of all expenditures for family living only among very low-income groups and among large families; 25 percent or less was spent for food by the well to do. A proper appreciation of the value of nutritionally adequate diets might lead families to allocate a somewhat larger proportion of their incomes to food.

The question is often asked whether families, particularly those at low-income levels, would spend appreciably more for food if incomes were increased, or whether the extra money would go chiefly for automobiles, clothes, or other uses. The income bracket in which a family is found seems to influence the share of an income increase that probably would be put into food. A preliminary analysis of the spending ways of families in different classes in 1935–36 indicates:

When an extra $100 for living expenses is available to families in the $250–$500 income class, an average of about $33 extra tends to go for food in the case of farm families and $37 in the case of city and village families.

In the $500–$1,000 income class, an extra $100 for family living expenses means about $18 extra for food in the case of farm families and $27 in the case of village and city families.

In the $1,000–$1,500 income class, an extra $100 for living expenses means about $9 additional for food in the case of farm families and $22 in the case of village and city families.

Village or city families with $3,000 or more a year for family living expenditures probably would average not more than $3 additional for food out of an extra $100 for all expenditures for family living.

Low-income families—especially those with incomes under $750 a year—are the ones that need more and better food; they are the ones that probably would spend a goodly share of an increase in income for food.

Something like $60 a year extra (at 1936 price levels) would be needed to buy the extra protective foods—eggs, milk, butter, fruits, and vegetables—needed by poorly fed families of average size to make up the difference between present diets and the plan for the economical fair diet referred to. These figures are minimal, since it is scarcely to be expected that all of the extra money for food would be spent for the food groups named. It may be expected that families living on $250 to $750 a year would spend $60 extra for food only if they have an increase of at least $150 to $250 for all living expenses.

It is evident that low-income families need further opportunity and greater ability to produce industrial goods or services if they are to have purchasing power sufficient to buy the farm products they need. The question here is whether industrial production can be increased sufficiently to provide income increases of the required magnitude.

Lowering food prices while maintaining present incomes could mean that the same number of dollars, with their increased purchasing power, would be available for food, and that better diets could be bought at each income level. But a reduction in food prices (relative to incomes and other prices) does not always result in proportional increases in the consumption of food. The purchasing power thus gained may lead to an increase in the consumption, not only of the foods for which prices have changed, but also of clothing, transportation, education, or other items, according to the family's standard of living.

Even if all the additional purchasing power were devoted to food, consumption of every kind of food would not increase at the same rate. While a significant decline in the relative prices of certain foods has been known to take them out of the luxury class—for example, citrus fruits, once available only to the wealthy, are now common articles of consumption—this would not be true of every food. Bread purchases, for instance, might not increase much in spite of relatively low prices. On the other hand, consumption of milk and meat might increase faster than prices fell.

Families at the higher income levels tend to consume considerably more fruits, succulent vegetables, eggs, meats, butter, and milk than low-income families, but not much more grain products, sugar, fats (other than butter), potatoes, and dry mature beans and peas. Hence it seems probable that if prices of food were reduced (relatively, of course, to incomes and other prices), the consumption of the latter groups of food products would increase comparatively little, and most of the released purchasing power devoted to food probably would be spent mainly on other food groups.

The question here is whether prices of protective foods can be reduced, and how much reduction would be needed to increase the consumption of these foods significantly among low-income groups.

WISE FOOD SELECTION AND DIETARY ADEQUACY

Apart from deficiencies due to inadequate purchasing power, many families fail to secure satisfactory diets because they lack information about the fundamentals of nutrition. Village and city families face the problem of making the best possible use of the money available. For farm families, the problem is tied up also with planning home production and conservation of food to meet the family's needs. The same sum of money or the same amount of land and work can secure diets very different in nutritive value, depending on the combinations of foods selected.

While the chances for better diets increase with rising per capita expenditures for foods, owing chiefly to the purchase of larger quantities of milk, meat, eggs, leafy green vegetables, and fruits, to depend solely upon increased purchasing power to insure dietary adequacy would unduly postpone attaining the goal. According to a 1936 study, it was only among groups of families spending $6 or more a person a week for food to be prepared and served at home that adequate diets were attained by practically every family.

A better knowledge of nutritive values in relation to cost, together with an intelligent appreciation of the importance of dietary adequacy to well-being, could result in an increased proportion of good diets at every food-spending level.

Many agencies, public and private, are concerned with spreading information about food values, nutritional needs, food buying, and food preparation. Chief among these are the schools and colleges, the Extension Service, club study groups, health centers, and child welfare, public health, and nutrition clinics. Discussion, demonstrations, illustrated lectures, film strips, special pamphlets, and articles in newspapers and in popular periodicals help to bring the matter before the public.

Wise food choices and the development of skill in food buying and preparation can mean diets that are much better nutritionally for comparatively little or no increase in average food expenditures. Taking advantage of the fact that food prices are based primarily on costs of production and distribution and on the interplay of supply and demand rather than on the nutritive values of food, many agencies, including the Bureau of Home Economics, have evolved several broad patterns for food budgets suited to different economic levels or different types of home food-production programs. (See Planning for Good Nutrition, p. —.) Such diet plans, stated in general terms, can be adapted to markets in any part of the country or to any of the more important land-use areas with their differing programs of food production for home use and still leave considerable room for catering to family tastes.

The motive behind such educational programs has been effectively put by McLester in his presidential address to the American Medical Association in 1935 (*736*):[2]

> In the past, science has conferred on those peoples who availed themselves of the newer knowledge of infectious diseases better health and a greater average length of life. In the future it promises to those races who will take advantage of the newer knowledge of nutrition a larger stature, greater vigor, increased longevity, and a higher level of cultural attainment. To a measurable degree, man is now master of his own destiny where once he was subject only to the grim hand of Fate.

The question is whether the general public can be persuaded that the matter is worth its attention and worth the price.

THE PROBLEM OF INCOME AND ITS DISTRIBUTION[3]

by Marius Farioletti[4]

ATTAINING the goal of adequate nutrition for all persons at all levels of income is only a part of the problem of attaining a higher consumption of all goods and services. It may be examined from several different viewpoints so far as raising the purchasing power and real incomes of at least the lower third of the Nation's families and single individuals is concerned.

Even if it is assumed that family food expenditures would be made on the basis of sound selection of foods at minimum cost, most of the low-income families—especially those with incomes under $750 a year—probably could not afford economical fair diets at a level of food prices such as existed in 1936. Almost 32 percent of the families and single individuals in the Nation received incomes under $750 in 1935–36. Over 27 percent of the Nation's families—exclusive of single individuals—realized incomes under $750. This low-income group needs additional purchasing power if it is to have a fair chance of achieving an economical fair diet.

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[2] Italic numbers in parentheses refer to Literature Cited, p. 1075.

[3] All 1935–36 income distribution data cited have been drawn from Consumer Incomes in the United States, of the National Resources Committee (*1160*).

[4] Marius Farioletti is Agricultural Economist, Consumers' Counsel Division, Agricultural Adjustment Administration.

THE SIZE OF THE NATIONAL INCOME

It was stated earlier in this article that families with incomes from $250 to $750 would probably spend an additional $60 for food if their incomes were increased by $150 to $250, and that this would give them a good chance of achieving an economical fair diet. The average income of the families in the levels of $250–$750 was about $520 in 1935–36. The average income of all families under the $750 level was about $460. Adding $250 to these two average incomes would raise the averages to $770 and $710, respectively. Suppose that increasing the purchasing power of all the families and single individuals receiving less than $750 up to an average of $750 would increase appreciably the ability to purchase economical fair diets, how big need the national income be to raise the average purchasing power of the families and single individuals receiving less than $750 up to the average of $750?

The amount would depend entirely on how the increase in purchasing power was made. Three possibilities will be given as examples:

(1) It is estimated that the 1935–36 national income received by families and single individuals aggregated $59,259,000,000, and that the aggregate family income—as distinct from that of single individuals—was about 80 percent of this total, or $47,679,000,000. If the incomes of the 32 percent of all families and single individuals receiving less than $750 were raised to an average of $750, and if the proportionate distribution of incomes were maintained as it was in 1935–36 for the 68 percent of the families and individuals that received $750 or over, the national income would need to be increased to about $98,000,000,000 (1935–36 values), as compared to the actual national income of $59,000,000,000. If a similar calculation is made on the basis of the 27 percent of the families who received less than $750 and 73 percent who received $750 or over, the aggregate income received by families—as distinct from single individuals—would need be increased to about $77,000,000,000, as compared to about $48,000,000,000 actually received by families.

These are large figures because if the distribution of incomes were not changed, all incomes would have to go up in proportion. Under these conditions, the value of the total output (in terms of 1935–36 dollars) would have to be increased 12 to 13 times the size of the additional purchasing power necessary to bring the low-income families and single individuals up to an average of $750. Any such increase, it need hardly be said, would have to be a long-run, not an immediate, objective.

(2) Suppose that any increase in the national income could be directed solely to increasing the purchasing power of the low-income families and single individuals up to an average of $750, leaving other incomes unchanged. In this case the necessary increase in the national income would be less than $4,000,000,000 (1935–36 values) for families and single individuals, or a little more than $2,000,000,000 for the families alone. Either of these increases would be more than achievable with the existing capacity to produce. Here the problem would be not so much how to increase the national income as how to direct

the additional income specifically to the low-income families and single individuals.

(3) Suppose that with a total income of the same size as the 1935–36 national income, an additional 2 to 4 billions of dollars of purchasing power could be diverted from the families and single individuals in the higher income levels to the families and single individuals in the level below $750. In this case an approximation to the goal of adequate nutrition would be immediately achievable in the sense that no increase in the size of the national income would be necessary.

These three examples have been presented solely for the purpose of showing the nature of the problem and limiting the scope of the discussion. The great range in the estimates, which run from a zero increase in the national income to an estimated increase of $39,000,000,000, indicates the difficulty of choosing definite policies because several combinations of the various possibilities probably would lead to attaining the goal. Other examples could be given. These serve to indicate the importance of the distribution of incomes and the factors affecting it.

THE DISTRIBUTION OF INCOMES

How was the $59,259,000,000 estimated to have been received by the Nation's families and single individuals in 1935–36 distributed among them?

One-half of the families and individuals received incomes under $1,070. They got 21 percent of the aggregate income. The other half realized incomes of $1,070 or over and got 79 percent of the aggregate income. Thirty percent of the families and individuals received incomes under $720,[5] and got about 9 percent of the aggregate income. At the top income levels, 30 percent of the families and single individuals received over 62 percent of the aggregate income. The middle 40 percent of all families and single individuals received about 29 percent of the aggregate income. It is a startling fact that individuals and families with incomes as low as $1,540 have to be included in any reference to the 30 percent in the top income levels.[6]

Most of the Nation's families and single individuals received incomes smaller than the average for all families and individuals. For example, in 1935–36, the average income for all families and single individuals was $1,502. However, 69 percent of the Nation's families and individuals received incomes under $1,500 and got only 36 percent of the aggregate income.

This distribution of income is often called a "maldistribution." What is a maldistribution? Is it a concentration of wealth? [7] Is it a concentration of income? In 1935–36 the highest 10 percent of the income recipients received $2,600 and over and got about 36 percent of the aggregate income. However, over half of this went to the 2 percent of the income recipients receiving $5,800 or over. The lowest 10 percent of income recipients were under the $340 level and obtained less than 2 percent of the aggregate income. The fact that 10 percent of the families and single individuals received 36 percent of the aggregate income may not appear to be a glaring concentration when it is realized that persons receiving incomes as low as $2,600 have to be included, but the inequality does appear to be glaring when the physical needs of the lowest 10 percent are considered in relation to their incomes of under $340.

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[5] About 32 percent received incomes under $750 and got less than 10 percent of the aggregate income.

[6] The aggregate income of $47,679,000,000 estimated to have been received by the Nation's families—as distinct from individuals in 1935–36 was distributed in about the same proportions, although the levels of income were higher. One-half of the families received incomes under $1,160 and got 21 percent of the aggregate family income. The other half received incomes of $1,160 or over and got 79 percent. Twenty-seven percent of the families received incomes smaller than $750 and accounted for less than 8 percent of the aggregate family income. Twenty-seven percent of the families received incomes of $1,750 or over and got about 59 percent. The middle 45 percent received about 33 percent of the aggregate family income.

[7] Allyn A. Young, Do Statistics of the Concentration of Wealth in the United States Mean What They are Commonly Assumed to Mean? (*1876*).

EMPLOYMENT AND THE DISTRIBUTION OF INCOMES

The long-time problem of achieving a higher consumption level is in large part the problem of increasing the productive capacity of the Nation's economic plant in the sense that a full utilization of resources will mean full employment of the Nation's labor power. It includes not only the full utilization of existing physical productive capacity and the consequent reduction of cyclical unemployment but also a building up of the Nation's economic plant in order that an adjustment to the problems of long-time unemployment may be made. It may appear academic to say that a "correct" distribution of national income is one consistent with attaining and maintaining full employment of our human resources. Nevertheless, it is a starting point for analyzing the probable direction of change if a change in the distribution appears necessary to attain the objective.

It was pointed out that a national income of about $100,000,000,000 would be needed if all incomes were increased proportionately to raise those at the lower levels up to $750 a year. Suppose that this $100,000,000,000 national income, in terms of 1935–36 values, were achievable within the limits of our physical and human resources along with our technical knowledge of how to produce goods and services efficiently, and suppose that it would mean a substantially full employment of labor. Would it still be possible to maintain the present distribution of incomes?

A concentration of a large part of the national income in the hands of a very few people, as in the prevailing distribution of incomes, is conducive to a relatively high ability to save. When the national income is increasing, this high ability to save appears to increase, in some periods, at a faster rate than do the opportunities for profitably coverting the savings into new capital goods. The inability to convert savings into what appear to be profitable forms of production takes the savings out of the flow of purchasing power. That is, savings which result in capital formation (new investment for production) provide workers with purchasing power to obtain consumption goods and services; savings that lie idle are not distributed to workers. As a result, the Nation's total purchasing power available for consumption does not increase enough to maintain prices that would tend to effect a full utilization of the increasing capacity to produce.

On the other hand, if the prices of consumers' goods and services could be decreased so that they could be bought even with a low level of consumer incomes, a high level of output could presumably be maintained, and the opportunities for converting savings into profitable investments would not decrease in spite of the increasing volume of savings.

In other words, when most of the people receive incomes below the average, industrial price policies and the large-scale production of consumption goods and services must be adjusted to the purchasing power of low-income families—on the farms and in the cities—if the savings at a high level are to be converted into new capital goods. New capital formation is to be expected whenever savings appear to be convertible into profitable investments. But these low prices must be effected by increased efficiency in production, which in turn has been brought about in combination with the new capital formation; for low prices do not induce the conversion of savings into new capital formation when the prices are unsound and are brought about solely by economic distress. When consumer purchasing power is high because of high productivity, the prices of consumers' goods are relatively low. When consumer purchasing power is low because of inefficiency and unemployment, even though prices of consumers' goods are so low as to bankrupt producers, they are nevertheless high in relation to purchasing power. Inflexible price policies, such as may exist under imperfectly competitive conditions, or the creation of new capital goods that cannot effect price reductions (that is, capital goods that are not self-liquidating) are inconsistent with the fact that most of the people receive incomes below the average, and therefore defeat their very purpose—production for profit.

Certain national and international growth factors may more than offset the difficulty of maintaining an increasingly larger number of profitable investment outlets for a high level of savings. These factors demand large volumes of new investment continually, and therefore tend to favor a distribution of incomes that brings about a high level of savings. Some of the major factors that in the past provided great opportunities for profitable investment through growth have been:

(1) The exploitation of new frontier resources. The physical building up of the Nation's ability to produce has demanded great volumes of savings to undertake the profitable opportunities presented.

(2) New inventions that promised to cut costs of production significantly and required large aggregations of plant and equipment to exploit the techniques involved.

(3) New industries and new ways of satisfying old wants, such as the automobile.

(4) An increasing population, and the consequent increasing demand for durable consumers' goods, such as housing.

(5) An increasing foreign demand for our savings, capital goods, and consumers' goods.

In the past, various combinations of these growth factors were so greatly increasing the demand for new capital formation that the United States annually borrowed large sums from foreign countries. In fact, we were net borrowers of foreign savings until the World War. Our history has been one of spectacular expansion, and it may be said that we needed a distribution of incomes that effected large volumes of savings to facilitate the desired capital formation. During this period the distribution of incomes could not be called a maldistribution in the sense that it effected too large a volume of savings.

Nor was it maldistributed in the sense of causing low levels of consumption, for the consumption levels increased significantly along with the capital formation. The Nation's increasing employment and national income oscillated up and down, but as long as the factors of growth were potent enough the main course was definitely upward.

Today, when the factors of growth have either disappeared or are not operating, we must look for alternative ways to increase the volume of employment and national income. With a large volume of idle savings and idle man power the question is whether we still need a distribution of incomes that permits high ability to save. Idle savings do not provide the Nation with greater ability to produce. They do not provide work for the unemployed. Nor do they provide low-income people with purchasing power to buy the consumption goods and services they need to maintain their health and welfare.

The continued accrual of large sums of idle savings suggests the need of a change in the proportions of the distribution of incomes, insofar, at least, as it would facilitate the attainment of a higher level of employment and a higher level of consumption. If a larger portion of the national income were directed to low-income families and individuals who would buy the goods and services that the Nation's farms, factories, and labor stand ready to produce, consumer demand would be increased appreciably and the savings of the Nation again would find profitable investment opportunities. Such a change would force the economy to utilize more completely its existing capacity for producing goods and services. As the Nation's ability to consume was increased, its proportionate ability to save would be decreased. This would tend to effect a balance between savings and capital formation, and once again the Nation could work its way up to a higher level of employment and consumption. The object of such a change would be to eliminate only idle savings, on the theory that idle savings like idle men reflect a social unbalance that cannot be allowed to continue.

If it is true that the prevailing distribution of incomes is the source of these idle savings, a way must be found to invest them in ventures that promise to increase the real income of our people, or else a way must be found to redistribute them. That is, finding a way to invest idle savings usefully is an alternative to redistributing the income. However, if the idle savings are not employed they will be eliminated, in the process of economic deterioration, by capital depletion and the exigencies of unemployment.

MORE DURABLE CONSUMERS

Besides the possibility of increasing all incomes proportionately, it was pointed out that the purchasing power of those at the lower levels might be raised by directing a small increase in the national income to them, or by diverting an equivalent amount to them from present higher-income levels. In other words, if the Nation believed that adequate diets for all of its people were necessary to protect its health and welfare, it would not need to wait for a great increase in employment and an enormously increased income to achieve this goal. Through Government aid it could place otherwise idle savings in the hands of people who would spend them for the necessities of life. This would also tend to increase the demand for the products of farm and factory and limit deflationary forces.[8]

It is a truism that in periods of great economic disorder, Government aid is the only large-scale alternative to destitution for large numbers of citizens. The real costs of relief to a nation are the economic, social, and political consequences of not providing adequate relief. Adequate relief includes adequate diets. Malnutrition for large numbers of citizens means physical and mental depletion of human resources. Hungry people do not produce a rich nation. Sick people do not produce a rich nation.

As a Nation we are constantly striving to finance the production of durable producers' goods and the consumption of durable consumers' goods. But how about the durability of the consumers? Adequate diets would make consumers more durable citizens and workers. How practical is the suggestion that some means of financing adequate diets be found? If an adequate diet made the consumer more durable and more productive over his life span, would not his greater durability decrease national health costs? Would not his greater productivity decrease production costs? Would not these decreased costs offset the cost of financing adequate diets? What is the value to the Nation of a more durable consumer?

Relief to the needy during periods characterized by various forms of capital depletion has the added advantage of limiting the effects of deflationary forces. Moreover, if the sums expended were large enough, it might be expected that the deflationary forces would be completely offset or even reversed through the cumulative effect of additional employment of men and savings. Financing adequate diets for low-income families and individuals would materially lessen the depressing effects of surplus agricultural foodstuffs.

ADEQUATE NUTRITION AND AGRICULTURAL SURPLUS

A strong force contributing to the agricultural surplus problem and limiting agricultural adjustment is the inability of consumers—on farms and in cities—to purchase adequate amounts of food at prices that tend to maintain the farm family's health and labor efficiency as well as the farm plant. About 40 percent of the nonrelief families who received incomes below $780 in 1935-36 were farm families. Lower farm prices for foodstuffs will not help many of these low-income families to attain the goal of adequate nutrition. In fact, farm prices that are too low mean liquidation not only of the farm family's health and labor efficiency but also of agricultural capital including the fertility of the soil, which is the largest part of the farmer's capital. The result is higher food prices in the future. The fertility of the soil is not reproducible in the same sense as is a manufacturing plant or machinery. Maintaining the fertility of the soil, like maintaining public health and labor efficiency, is of paramount importance to the future.

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[8] It may be pointed out that governmental policies designed to increase consumption directly, as distinct from those designed to aid producers directly, may be viewed as indirect aids to industry. This is true particularly when Government policy increases consumption significantly, or retards a decrease, at the same time that industrial operations are appreciably less than optimum. These policies are not startling innovations in governmental action. Many Government policies, both historical and current, affect the distribution of incomes. That is to say, Government aids directed at both the lower and higher levels of income already exist. The former include such readily recognizable forms as unemployment relief, aid to dependent children, and assistance to the blind; the latter, direct grants and loans to industries, and protective tariffs. What is weighed in the balance is the design of the aid and not its precedent.

Though lower farm prices of foodstuffs may give some low-income consumers an immediate advantage in purchasing better diets with small incomes, lower prices to consumers for food-distribution services[9] and other nonfood goods and services would be even more helpful, provided incomes were not decreased as a consequence of the decreased prices.

The dollar cost to the Nation of financing adequate diets for low-income families and individuals should be compared with the costs of ill health, lowered productivity, and lost working time due to malnutrition. When surplus foodstuffs exist at the same time that inadequate diets prevail among low-income groups, another strong justification for the public financing of adequate diets is the relief afforded to farmers and the Nation by limiting the deflationary effects of surpluses. However, adequate diets for many low-income families and individuals need to be subsidized just as much when there are no price-depressing surpluses, for then food prices are higher while the incomes of many people are not. Food subsidies need to be extended to undernourished, needy people whether or not surpluses exist, and an adequte subsidy program designed to increase the food-purchasing power of needy people has advantages over a program that distributes surplus foods directly.[10]

SUBSIDIZING CONSUMPTION OF FOODS

by F. V. Waugh[11]

FROM one standpoint, the most fundamental approach to the joint problem of agricultural surpluses and undernutrition would be to combine education and research in nutrition with public policies designed to increase the earning power of the low-income groups of the population. But it must be admitted that very little seems to be known about practical ways to increase the earning power of these groups. Though a start has been made by the establishment of minimum wages, unemployment insurance, and old-age pensions, it is clear that there is a long way to go before poverty and want will be abolished.

MORE EFFICIENT METHODS OF PRODUCTION AND MARKETING NEEDED

Families whose incomes are so low that they cannot now afford adequate diets would be benefited about equally either by an increase in earning power or by a drop in the price of food. In the long run it is possible to have lower prices of food only with the development of more efficient methods of production and marketing.

A large part of the research done by both the Department of Agriculture and the State experiment stations has been devoted to a search for methods of producing agricultural products at the lowest possible cost. This includes research on plant and animal breeding, the use of fertilizers, crop rotations, the control of insect pests and diseases, the development of efficient farm machinery, and many other important lines of work.

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[9] There have been cases when foodstuffs have involuntarily wasted on farms because low-income consumers could not afford to pay the distribution costs.

[10] Eating the Surplus—address by Milo Perkins at a meeting of the National Association of Retail Grocers, Kansas City, June 21, 1939.

[11] F. V. Waugh is Principal Agricultural Economist, in charge, Division of Marketing and Transportation Research, Bureau of Agricultural Economics.

A smaller but important part of agricultural research has been devoted to the development of efficient methods of marketing. Substantial improvements in marketing have resulted from this work. They include, for example, the adoption of official grades, standards, and inspection for certain products; the development of widespread and detailed services of crop and livestock statistics and market reporting; and the regulation of certain marketing methods and practices. This research has also been very useful in developing sound policies for farmer-owned cooperative associations for buying farm supplies and selling farm products.

There is room for more progress in the development of efficient methods of production on the farm, and only a fair start has been made in developing efficient methods of marketing. The latter field remains largely unexplored and seems to offer substantial possibilities for increased efficiency that would benefit both the farmer and the consuming public.

As indicated in table 2 the American farmer ordinarily gets less than half of the money the city consumer spends for food.

TABLE 2.—*Estimated retail value and equivalent farm value of 58 foods purchased annually by a typical American workingman's family* [1]

Year	Retail value	Farm value	Distributors' margin	Farm value as percentage of retail value
	Dollars	*Dollars*	*Dollars*	*Percent*
1913	252	134	118	53
1923	384	173	211	45
1929	415	195	220	47
1932	270	88	182	33
1936	342	152	190	44
1937	353	160	193	45
1938	321	130	191	40

[1] Estimates of annual purchases of foods by a typical workingman's family were obtained from the 1918-19 Cost of Living Survey made by the U. S. Bureau of Labor Statistics. The 58 foods include meat, dairy and poultry products, bakery and cereal products, a number of fresh and canned fruits and vegetables, and several miscellaneous items. Retail price data are from the Bureau of Labor Statistics; farm price data are mostly estimates of the Bureau of Agricultural Economics.

Table 2 shows, for example, that in 1938 a typical American workingman's family spent $321 in purchasing the 58 foods included in the study. Of this $321 spent by the consumer, the farmer received $130 and the other $191 went to pay the various charges for transportation, processing, and marketing. Not only do these costs represent a high proportion of the consumer's food dollar; they also tend to be relatively stable, not responding quickly to changes either in business conditions or in the incomes of consumers and farmers. The relative inflexibility of marketing charges results in extreme variations in prices at the farm. For example, in a period of declining business activity and decreasing employment, retail prices of foods in cities tend to drop fairly slowly, but because the costs of marketing are rather fixed this results in a large proportional drop in the prices received by farmers.

Not only the farmer but the public as a whole would benefit decidedly from any substantial increases in the efficiency of marketing or from any practical method of bringing about a desirable flexibility in marketing charges in order to prevent violent price swings. The very fact that marketing costs and charges account for over half of the retail value of foods indicates that efficient marketing is necessary if foods are to be sold at a price that will encourage better nutrition. However, it will not do simply to complain of the high cost of marketing and to condemn the present marketing system as inefficient. The present system can be called inefficient only when it is possible to point out definite, practical ways of improving it so that foods can be handled at lower costs.

The Department of Agriculture is giving increased attention to this problem. Results of some of its recent studies indicate several practical possiblities for reducing marketing costs. Among them are the reorganization of market facilities and the better regulation of their use; the development and maintenance of low-cost outlets such as push-cart markets and farmers' curb markets; the more effective use of methods of mass production and distribution in the marketing of farm products; and special drives to increase the volume of foods handled and thus to reduce the unit cost of distribution.

MAKING USE OF SURPLUS FOODS

FREE DISTRIBUTION

Perhaps the simplest and most direct method of meeting the farm-surplus problem and at the same time combating undernutrition is for the Government to purchase surplus commodities and distribute them through relief agencies to destitute and undernourished families. Since 1935 the Federal Surplus Commodities Corporation has been cooperating with local welfare agencies on such a program. This program has been of definite benefit to both farmers and consumers. When surpluses are so big that the market price does not cover harvesting and shipping costs, both the farmer and the consumer lose. For the farmer such a surplus means practically a total loss of income from the crop. For the consumer it usually means a complete waste of unharvested food that people need and also the danger that the disastrously low prices at the farm may discourage production in the future and bring about shortages that will be very harmful.

During the past 4 years the Federal Surplus Commodities Corporation has bought and given to welfare agencies almost 3,000,000,000 pounds of surplus foods. These products have contributed to the nutrition of needy families. In many cases these families have learned to use protective foods that they had not previously been consuming. The following tabulation indicates the amounts of several foods distributed during the 4 years:

	Million pounds
Meats and fish	932
Grain products	450
Potatoes, sweetpotatoes	450
Other vegetables	115
Fruits	565
Cheese, dry skim milk, evaporated milk	133
Butter, lard, other fats	104
Sugar, and sugarcane and sorgo sirups	26
Eggs	14

Farm surpluses must not be allowed to go to waste when there are thousands of needy families who are not getting enough food. The free distribution of surpluses to such families is one of the simplest ways of meeting the situation. There are, however, two difficulties from the standpoint of nutrition: (1) The particular foods of which a surplus exists at any time may not be the foods most needed in the diets of relief families; and (2) since this form of free distribution must be limited to destitute families, it does not offer a very large outlet for surpluses, at least in normal times.

MAKING SURPLUS FOODS AVAILABLE TO LOW-INCOME FAMILIES

In addition to the free distribution of surpluses, therefore, the Department of Agriculture is naturally interested in any other practicable methods of expanding the use of surplus foods by making them more readily available to a fairly large group of low-income families.

The Department has been studying in some detail several approaches to this problem. One of the simplest is the encouragement of special low-cost methods of marketing. To a certain extent this might be accomplished by research and education of the type familiar in commerce and industry, but in other cases it may require some kind of subsidy in order to promote low-cost types of markets, the use of cheap packages, and the elimination of expensive processing and manufacturing methods. Such a program should be effective in moving surpluses of certain foods to market and making them available at low prices to families who are not able to afford the more expensive grades of foods and the expensive services that commonly go with them. If a program of this kind could be kept flexible, it might be possible, even in the case of a large surplus, to move a large part of it through the low-cost channels and make it available to low-income groups without greatly disturbing the price in the rest of the market. The prices of the best grades or the most refined forms of these foods might be kept fairly stable so that farm income could be maintained at a reasonably satisfactory level so far as it depended on the marketing of these grades.

A somewhat similar plan would be the conversion of surpluses into lower-priced products. For example, surplus milk or eggs might be dried and made available at comparatively low prices. Surplus meats might be ground or manufactured into products that could be sold at prices substantially below those of the usual market cuts of meat. In a similar way surplus fruits might be made into juices or other foods that could be made available at low prices. Such a program would move more surplus products into consumption than are being moved at present and at the same time would benefit undernourished families. The lower-priced products probably would be bought mainly by families who could not afford these foods in their usual forms, or who could afford to use them only in small quantities. Families with moderate to high incomes doubtless would continue to buy fresh milk, fresh eggs, fresh meats, and fresh fruit.

Another possibility is the sale of surpluses at special low prices in distress areas where there is a large amount of unemployment, where wages are very low, or where, for any other reason, malnutrition may be especially prevalent. Such a program might be carried out in fairly large distress areas. For example, surplus foods might be distributed at low prices in a coal-mining area, including parts of several States. On the other hand, if it could be properly regulated a program of this kind might also be adapted to small areas within a city. In most large cities there are definite areas of low incomes and undernutrition. It might be possible to work out practical methods of distributing surpluses at low prices in such areas, although it is obvious that the problem of administration would be much more difficult than in the case of a large area.

The Stamp Plan

Methods such as those suggested are well worth considering and trying, but they all approach the problem rather indirectly and perhaps would not benefit either the farmer or the consumer so much as a plan specifically designed to give low-income families a greater purchasing power for foods. Several such plans are being studied in the Department. Some of them would give a higher purchasing power for all foods and some for a limited number of foods. The stamp plan now being tried experimentally in several cities combines both. The families eligible to take advantage of this plan are those eligible for Federal, State, or local relief. When they buy orange-colored food stamps they are given a certain number of blue stamps usable only for purchasing foods designated as surplus. This plan gives this low-income group an increase of purchasing power for foods in general of about 50 percent, but in effect it also gives them a special inducement to increase their purchases of foods that are particularly abundant.

It is too early to evaluate in any detail the results of the stamp plan. These results should be studied very carefully and objectively. The plan is being tried as an experiment in the hope that practicable and suitable ways of meeting at least part of the problem outlined in this article may be found. There are many other ways that are well worth considering. The stamp plan can be greatly modified if experience indicates that changes are desirable, or it can be abandoned if something better can be found to take its place. However, the problem is so important, both to agriculture and to the consuming public, that any method offering a reasonable possibility of a solution should be given an honest trial.

AGRICULTURAL PROGRAMS AND THE NUTRITIONAL GOAL

by J. P. Cavin[12]

Providing adequate diets for the entire population of the United States would in the long run involve more than the education of consumers, the provision of special market facilities of one kind or another to get rid of surpluses, and even increased incomes. It would involve certain rather far-reaching adjustments in agricultural production, in some cases supplementing, in some cases counteracting, those already under way.

Agriculture has the task of providing the raw food material for feeding the Nation. It already contributes materially toward the goal of superior nutrition by supplying the market throughout the year with important foods at reasonable prices.

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The maintenance of adequate supplies of food and fiber is and undoubtedly will continue to be a major criterion in establishing the goals of agricultural adjustment. No one can challenge the objective of providing our present and future population with supplies of food sufficient for good health and nutrition. As Viscount Astor and B. S. Rowntree said in a recent report on British agriculture (*44*):

> It seems probable, indeed, that the improvement of the standards of nutrition will come increasingly to be regarded as an important aim of national policy analogous to the improvement of sanitation in the pre-war and of housing standards in the post-war period.

When dietary standards are formulated strictly from the point of view of nutritional needs, they indicate that there should be considerable changes in dietary habits and increased expenditures for food on the part of the bulk of our population. Hence such standards constitute an ideal or a long-run goal rather than one immediately attainable.

GOALS OF AGRICULTURAL ADJUSTMENT PROGRAMS

To the extent that dietary adequacy is introduced as a criterion in the establishment of goals of agricultural adjustment for action programs, it must be both attainable and consistent with other valid objectives. In recent years, these other objectives have been principally (1) adjustment to export demand, (2) soil conservation, and (3) the economic and social well-being of agricultural producers. This interplay of objectives appears in the declaration of policy of the Agricultural Adjustment Act of 1938, which states that the act was designed, among other things—

> for the purpose of conserving national resources, preventing the wasteful use of soil fertility, and of preserving, maintaining, and rebuilding the farm and ranch land resources in the national public interest; . . . to assist in the marketing of agricultural commodities for domestic consumption and for export; and, with respect to the commodities specified in the act, for assisting farmers to obtain, insofar as practicable, parity prices for such commodities and parity of income, and assisting consumers to obtain an adequate and steady supply of such commodities at fair prices.

In introducing consumption requirements as a determinant of the goal of agricultural adjustment, it has been usual to take as a criterion some recent average level of consumption adjusted for population increase and for trends in the consumption of individual products. Thus under the present adjustment act, a normal year's domestic consumption is defined as the annual average quantity consumed in the United States "during the 10 marketing years immediately preceding the marketing year in which such consumption is determined, adjusted for current trends in such consumption." In establishing annual marketing quotas under the Sugar Act of 1937, for example, the Secretary of Agriculture is required to fix them at such a level "that the supply of sugar made available . . . shall not result in average prices to consumers in excess of those necessary to maintain the domestic sugar industry as a whole," and shall not be less than "the quantity of sugar required to give consumers of sugar in the continental United States a per capita consumption equal to that of the average of the 2-year period 1935–36."

The justification for using a statistical average as a norm is to be found in the remarkable stability of the average per capita consumption of all food products in the United States since 1920, from which year fairly complete data are available. During the 18 years 1920–37 the average annual per capita consumption of all food products, in terms of estimated weight available for sale in the retail markets, was 1,446 pounds. During the boom period 1925–29, when consumer income available for living was at a peak, consumption averaged 1,476 pounds, or only about 2 percent above the average for the entire 18-year period. There was no significant decline during the depression following 1929, as consumption during the period 1930–33 averaged 1,442 pounds per capita, which was only a fraction of 1 percent below the average of the entire post-war period.

This suggests that, given the existing eating habits of the Nation (including trends in the consumption of specific foods) and the existing distribution of income, the total demand for food in the United States approximates a definite physical requirement that depends primarily on the size of the population. The consumption of specific foods, such as sugar and certain canned products, tends to vary directly with consumer income, but this movement is overshadowed by the more stable forces in the situation. From the point of view of national agricultural policy, this analysis indicates that proposals for establishing, as an integral part of action programs for agriculture, national goals substantially in excess of recent actual consumption, must be carefully examined with a view to determining whether effective means for securing these desired increases can be put into operation.

In determining acreage and production goals for basic crops under the Agricultural Adjustment Act of 1938, the requirements of normal exports and normal reserve stocks are added to those of normal domestic consumption. Normal exports are 5- or 10-year averages adjusted for current trends, while normal stocks vary from 7 percent of a normal year's domestic consumption and exports for corn to 175 percent of a normal year's domestic consumption plus 65 percent of a normal year's exports for tobacco.

PRODUCTION REQUIREMENTS UNDER PRESENT STANDARDS

Before proceeding to the problem of the interrelations of agricultural adjustment programs and programs designed to raise the nutritional level on a Nation-wide scale, the results of the application of the criteria of average per capita consumption, adjustment to foreign demand, soil conservation, and adequate farm income to the American agricultural problem will be briefly surveyed.

During the 5-year period 1928–32, our total harvested cropland averaged about 365 million acres. With normal growing conditions, and in the absence of control measures or the diversion of soil-depleting acreages to soil-conserving uses, a return to this high level might easily take place. Assuming average yields and a population of 130 million persons, 260 to 265 million acres would be required to maintain average per capita consumption of food and fiber at the level prevailing during the period 1920–29. If 40 to 45 million acres of feed grains and hay for work stock are added to this, and 25 to 30 million acres to care for probable export demand, the result is a total harvested acreage requirement of 325 to 340 million acres. This is 25 to 40 million acres below the 1928–32 average. Even if our 1930–34 export market of approximately 45 million acres should be regained, which seems extremely unlikely, total acreage requirements would still be about 15 million acres below the 1928–32 average. Reductions of such magnitudes are consistent with the requirements of soil conservation and good farm management, which indicate a downward adjustment of 20 to 30 million acres, and with the requirements of parity income, which indicate a reduction of 30 to 50 million acres, depending primarily on the general price situation in agriculture.

In summary, the application of these several criteria indicates a reduction below the 1928–32 average of 365 million acres lying somewhere between a minimum of 15 to 25 million acres and a maximum of 35 to 50 million acres. The reduction appropriate to any given year would vary with changes in the relative weights given to the several criteria, which in turn would be influenced by such factors as the supply conditions existing in agriculture and the state of domestic and foreign demand.

PRODUCTION REQUIREMENTS IF DIETARY STANDARDS ARE TO BE RAISED

The problem of agricultural production will now be reexamined with special reference to the need for raising the consumption of food in the United States above existing levels or altering appreciably the structure of that consumption. This will involve an attempt to give approximate answers to three broad questions: (1) To what extent does an agricultural output geared to recent average consumption requirements approach or fall short of dietary standards established primarily from the point of view of nutrition? (2) What would be the effect on agricultural output if it were adjusted to provide the quantities of the several foods that nutritional standards would require? (3) To what extent is it practicable to introduce into agricultural adjustment a goal based on dietary standards conforming to a structure of consumption differing appreciably from that evidenced by actual consumption?

The over-all dietary standards discussed in this Yearbook have been formulated from two standpoints: (1) Securing the best nutritional values at four levels of cost, and (2) increasing the consumption of protective foods over the present average level of consumption in the Nation as a whole. The recommendations on the basis of cost give rise to four recommended diets, namely, an economical fair diet, a low-cost good diet, a moderate-cost good diet, and an expensive good diet. The desirable increases have been formulated in three ways earlier in this article: (1) Increases required to raise present average consumption to the level of existing freely chosen diets that can be rated good nutritionally; (2) increases required to raise present average consumption of families consuming less than the quantities specified for an economical fair diet up to the level of that diet; and (3) increases required to raise present average consumption to the level that would be attained if all families selected their diets according to plans adapted to their income.

It appears that the total acreage required to raise supplies of agricultural products sufficiently to enable the Nation to secure the moderate-cost good diet would be slightly higher than the total acreage required to maintain recent actual levels of per capita consumption. This diet provides for substantial increases in the consumption of a number of foods, including milk, certain fruits, and certain vegetables, which would necessitate an expansion in the acreage devoted to the production of feed crops and hay, to take care of the increases in milk, and in the acreages of fruits and vegetables. With the various adjustments involved, the total acreage required for domestic food consumption would be approximately 285 to 295 million acres, slightly higher than the 280 to 285 million acres required for the maintenance of recent levels of actual per capita consumption. This acreage is, of course, greatly in excess of the requirements of the two lower standards—the economical fair diet and the low-cost good diet.

If the Nation were actually able and willing to expand its consumption of food to conform with the "expensive good diet," it would probably be necessary to utilize about 30 to 40 million acres more than are needed to cover requirements based on actual recent consumption.[13] This would not only result in a tremendous improvement in national health, but would take us a long way toward a solution of the agricultural problem as a whole.

Of the dietary changes recommended from the standpoint of increasing the consumption of protective foods, those formulated on the assumption that all families select their diets according to plans adapted to their incomes appear to be the most promising. Could such selection be secured, the result would be substantial increases above the present level of consumption of protective foods. As indicated on page 381, consumption of milk might be increased 10 to 20 percent; that of butter, 10 to 25; of tomatoes and citrus fruit, 25 to 70; and of leafy, green, and yellow vegetables, 100 percent. It is difficult to estimate the precise effects of such consumption on acreage. Probably impending increases in the acreage of bearing trees will come close to providing the needed increase in citrus fruits. Close to a million additional acres might be needed for vegetables, including tomatoes. The greatest effect on agriculture would come from the desired increases in the consumption of milk and butter; probably 7 to 8 million acres more would be required to support the increased numbers of dairy cattle.

THE ROLE OF AGRICULTURE IN ATTAINING THE NUTRITIONAL GOAL

Granted that substantial increases in consumption along the lines indicated by the various dietary standards are possible, there would still remain the problems involved in attaining these nutritional goals, including the role that agriculture might be expected to play. Actual food consumption depends upon the interplay of a considerable number of factors, among the more important of which are: (1) Size of the total national income and its distribution; (2) eating habits; (3) consumers' knowledge of the economics of food purchasing, including knowledge of dietary values, opportunities for food purchasing, and dietary values relative to costs; (4) prices of food, which are a function partly of supply, partly of consumer buying power, and partly of the cost structure, particularly distribution costs.

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[13] In this connection it should be noted that there is not one structure of consumption that commends itself above all others, but rather a number of attainable structures, each of which embodies merits and defects, and each of which may indicate a somewhat higher or lower total acreage without thereby implying greater or less nutritional well-being.

The size and the distribution of the national income are important limiting factors to programs designed to increase the consumption of any commodity or group of commodities. Not until there is some real solution of the problems of industrial fluctuation and chronic underemployment of resources will it be possible to launch with confidence programs designed to increase the welfare of the total population along any particular front. The case for bettering the distribution of income rests upon strong grounds, both with respect to the welfare of the Nation as a consuming unit and with respect to the operation of an economy that probably needs to be geared to a lower rate of capital accumulation than has been characteristic of the last century or so. But here again the ways and means are nebulous and controversial, and important changes in the distribution of incomes in the near future cannot be taken for granted in formulating programs if their success depends upon such changes.

Eating habits and consumer knowledge of the economics of food purchasing are usually considered, and rightly so, as problems best attacked by education. There is no doubt that education in these spheres needs to be greatly expanded and intensified; but it is hardly feasible to ask agriculture to produce supplies of commodities appropriate to better nutritional goals unless the persons directing the educational programs can furnish evidence that their efforts will affect consumer demand in such a manner that the agricultural producers will not suffer economic losses from altering their structure of production.

The problem of distribution costs in relation to food prices has already been discussed, and attention will here be centered on prices in relation to supplies of agricultural products. The question has been raised as to whether agriculture can adapt itself to a changing demand, involving in particular an increased consumption of the protective foods, and also whether agriculture can anticipate the movement on the supply side and facilitate it.

There can hardly be any doubt about the ability of agriculture to meet changes in consumption evidenced by expansion in effective demand. As stated in the final report of the mixed committee of the League of Nations on the relation of nutrition to health, agriculture, and economic policy (*671*), "the best proof that agriculture is able to adapt itself to the expansion in demand for the protective foods lies in the fact that it is already doing so." The need for profitable outlets for agricultural products is so great that a quick response to increased demand seems inevitable.

Through its rapid adoption of cost-lowering techniques, agriculture has long been, and undoubtedly will continue to be, a powerful factor in the improvement of dietary habits. Furthermore, agriculture as a whole has characteristically turned out a relatively large and stable quantity of food products during both prosperity and depression. On the average this production has been so large in relation to demand that agricultural income has suffered, with the result that there has been a steady depletion of agriculture's greatest resource—the soil. It is difficult to see how further burdens in the production of foods can be thrown upon agriculture without an assurance of a fair return, particularly when the bulk of the recommended consumption is in the relatively high-cost foods. To attempt to do so would be to force the cost of a general food subsidy on agriculture and further depress it in relation to the rest of the economy. Large increases in consumption must come primarily from better consumer knowledge, increased national income, better distribution of income, and perhaps some subsidizing by the Nation as a whole of the food consumption in certain underprivileged groups.

Given desirable changes in these spheres, there is no doubt of the ability of American agriculture to respond with an appropriate output.

Part 2

ANIMAL NUTRITION

SOURCES AND CYCLES OF THE NUTRITIVE ELEMENTS

by E. J. Kraus[1]

THE soil, the atmosphere, the plant, and the animal are parts of a great cycle of life in which the same materials are used over and over again. This article shows how the cycle operates, how plants alone have the power to store up the energy needed by animals and man, and how they furnish other nutritive elements derived from the soil. The author makes a plea for a new, unified approach to the problems of nutrition, arguing that much can be done to control the nutritive value as well as the quality of plant products by proper cultural methods, beginning with the handling of the soil.

ANIMALS depend upon plants for their existence and both depend upon the soil, or rather the nutrients in the soil. People now take this for granted, although the recent publicizing of the use of water cultures has somewhat confused the issue by making soil seem unnecessary. The vast quantities of food obtained from rivers, lakes, and other bodies of water are ultimately derived from the nutrient salts that are present in the water and are constantly being renewed or added to from the land areas. These nutrient materials must be in solution in the water or in soil moisture before they enter the plant. After entrance they become a part of the vast complex of compounds that make up the plant body. They also make up the body of the animal that consumes the plant.

Attempts to determine which of these elements are essential, what their relative proportions for any desired type of plant development must be, and above all, the means of supplying them and providing for their renewal and replacement constitute the major portion of the investigative work dealing with plants. As scientific knowledge progresses, it becomes increasingly obvious that the whole cycle of interactions and interdependencies of plants and animals must be studied simultaneously. These must then be integrated in terms of the environment in which the plants and animals develop. By this method a comprehensive grasp of the biologic problem of agriculture may be gained, and the whole interpreted in terms of its social significance.

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HOW PLANTS STORE ENERGY

The vital or living process, whether in plant or animal, always involves a greater or lesser expenditure or release of energy. The source of this energy used by both plants and animals is food. Food occurs in a very great variety of forms and degrees of complexity, and technically the term would include many substances not commonly recognized as food. But whether foods are relatively simple or complex in their chemical make-up, their principal importance in the economy of the plant and animal worlds is due to the energy they yield.

In general, animals possess only the capacity of releasing energy from foods, whereas green plants have the capacity not only of releasing energy from foods but also of manufacturing food or accumulating energy in a form utilizable by themselves or animals. This is a very important function. The capacity of green plants for manufacturing food, that is, accumulating energy as food, places them at the forefront in any system of economy dealing with living things.

Green plants accomplish energy accumulation by decomposing carbon dioxide and water, two substances relatively low in energy content, and recombining a part of these products, in the presence of light, to form sugar, a substance relatively high in energy content and of great food value. The release of oxygen into the atmosphere during the process of decomposing carbon dioxide and water and making food is scarcely less important, for oxygen is essential to many animals and plants for the utilization of the energy stored in foods.

Without green plants all the higher animals existing today would eventually perish. They are completely dependent upon the foods made by green plants or stored in excess of their own needs for growth and development.

In addition to carbon dioxide and water the green plant requires for its living processes a fairly wide variety of other chemical elements, which are supplied to it from the soil, water, or the atmosphere. Without any one of these necessary elements, the plant cannot build up foods nor can it continue to live. Even though all these elements may be present in any given medium in which a plant may be living, there may be a wide variation in the relative quantities. It has been found that the character of growth and rate of development of a plant varies greatly with the abundance or scarcity of these various elements in relation to one other. One of the principal problems of the agriculturist is to determine these relationships and balances and to correlate the different types, quality, and quantity of plant growth with them.

On the basis of his knowledge of these relationships and balances it is possible for the agriculturist so to manipulate or alter the factors making up the environment of a plant that within rather wide limits he can produce the amount, kind, and quality of plant product he desires. The production problems of agriculture, whether in field, forest, garden, or greenhouse, are all of this sort, the chief difference being the degree of control of the environment exercised or economically possible. In a greenhouse, for example, many more environmental conditions are under control than in a forest or on open pasture land. What may be considered economical practices under one set of conditions would be quite out of the question under another.

THE WHEEL OF LIFE

The interrelation of the soil, the atmosphere, the plant, and the animal is a cycle in which the same materials are used over and over again. The sum total of elements in the world remains relatively fixed, but there is a more or less constant movement of them from place to place. At any particular location there may be a large accumulation at one time or a decided deficit at another.

The point of greatest concern in the living process is the amount of energy available in foods made of these elements. Minerals, moisture, and certain elements of the atmosphere, under appropriate conditions of light and temperature, find their way to and into the living green plant, which splits up many of the old combinations and forms new ones. Of these new combinations some represent great stores of potential energy capable of being released again by the same plant or other plants or animals. This process of food building and the storage of the excess not immediately used in life processes by either plant or animal could not go on indefinitely for the simple reason that eventually the free supply of elements out of which foods are built would be exhausted. Such exhaustion does not occur in nature because the living process goes through destructive, energy-releasing phases or cycles when the elements are again set free. They are then once more available to be rebuilt into a living system.

The common idea that green plants build up foods but do not destroy them is erroneous. During periods of darkness and very low light intensity plants use up large quantities of food. In fact they do this in bright light also, but the quantity is overbalanced by the amounts constructed. Such plants as yeasts and molds manufacture little or no new food, merely reworking that already formed and more or less completely destroying much of it. But they are of great value through these destructive processes in rendering available the materials out of which new foods may be made. Animals do the same thing by consuming the food stored up by plants and other animals, building part of it into their own bodies, and destroying much of it, which is released into the atmosphere or returned to the soil in simpler combinations. It may then be taken up again and built into new plant bodies.

Thus, a great cycle or wheel of life is established, constructive processes balancing the destructive. The basic elements are combined, taken apart, and recombined, the green plant being the principal constructive force, nongreen plants and animals the destructive. New individuals come into being and pass away again, but they are all made from the same stock of elemental substances, kept in circulation by the constructive processes of food manufacture and the destructive processes of food utilization, through the medium of green plants, nongreen plants, and animals. Sometimes storage in excess of utilization has resulted in vast accumulations of coal, oil, and similar materials, which when eventually burned or oxidized are also put back into circulation in forms that can be utilized by the green plant.

Minor cycles may be established for individual elements. For example, nitrogen is taken from the air, soil, or water into the plant body, where it forms part of a great variety of compounds, some of the most complex and important being the proteins. These plant proteins, as well as other nitrogen-containing compounds, may subsequently be built into the animal body, eventually to be broken down and reworked into simpler compounds and again excreted to the soil. Thence the simpler compounds may enter other plants directly, or they may be still more completely decomposed and utilized in whole or in part by growing plants. There are several types of the nitrogen cycle, some of them very complex, others more simple and direct.

Another important cycle is that of carbon. Carbon, in combination with oxygen as carbon dioxide, is universally present in the atmosphere. From that source it enters the living leaves of green plants, and in the presence of light and in a suitable temperature it is made into sugar, a basic food. This sugar may be at once destroyed and its contained energy released by the living matter of the plant, or it may be compounded, together with other substances, into literally hundreds of compounds which constitute some portion of the plant body or which may be stored in its cells. These varied forms of food may then be consumed by animals and used by them as a source of energy or be built into the still greater variety of substances which constitute the animal body. In any event these compounds also are eventually destroyed, and the combinations of carbon, of greater or less complexity, find their way back to the soil or directly into the atmosphere as the relatively simple carbon dioxide.

Thus, for every one of the more than a dozen chemical elements which are required for the growth of green plants, a cycle of greater or lesser complexity exists. A critical understanding of these cycles, the necessary provision for the most economical return of the various elements to the soil or atmosphere, and their conservation in such a place and manner that they can again become a part of any living organism desired in human economy, is the basic consideration in soil management and in plant and animal husbandry. Around this fundamental understanding, in which many elements still remain to be determined and classified, practices must be built. These practices may be simple and direct or vastly complicated. Their simplification, the finding of those practices which are least costly of human effort and involve the least loss of the various elements in the cycle of life, contributes directly to human welfare.

MINERAL CONTENT OF PLANTS

Many of the vitamins, or at least their precursors—the substances from which vitamins are formed—are obtained by domestic animals from plants in the same way as other food elements. Most of the essential minerals may be obtained from plants, but these may be gotten in other ways also, some of them by direct consumption of mineral compounds. At the present time, there are few fields in which knowledge is making greater advances than in the whole problem of mineral metabolism in both plants and animals. Viewpoints are constantly being shifted with added evidence. It is clear, however, that the chemical composition of plants, with respect to both their mineral and their organic content, may be greatly modified by the kind and amount of fertilizer applied to them, by irrigation, by pruning, and by many other factors. It is equally certain that the value of plants as food for animals varies with their chemical and physical make-up. For example, nutritional diseases result when animals are fed on plants grown on certain pasture lands low in calcium or phosphorus. It is readily possible to change markedly the food value of plants, either fresh or cured, through methods of treating and handling the soil on which the crop is grown. A fertilized pasture as compared with an unfertilized one may be very different in value as range for livestock, not only because of greater yields of the crop but because of better quality.

One of the most direct ways in which the composition of crops may be more or less regulated by the plant husbandman is through the kind, amounts, and time of application of fertilizers he adds to the soil. Different species or varieties of plants react in varying ways to the several elements which may be applied to soils, and specific practices must be devised for the many different relations of soil, moisture, and temperature that exist. The amount of soil nutrients and other substances entering the plant may vary greatly, though there is a lower limit of concentration below which plants will make no growth at all. This variation depends not only upon the amounts of nutrients in the soil, but also upon virtually every other cultural practice. When any available element is present in the soil in quantities somewhat greater than the amounts directly utilized by a plant for growth, building of tissues, and storage, compounds of the element, of greater or less complexity, may still accumulate within the plant body. This excess accumulation or what might be called luxury consumption of calcium, phosphorus, potassium, nitrogen, and many other elements is well known. An excess intake of mineral salts is of very great importance not only for its effect on the total quantity of plant tissue utilizable as feed for animals, but also for its effect on the quality of the feed.

Many experiments are being conducted in human and animal nutrition to determine the specific conditions in which the various mineral elements necessary for growth and development must exist within the plant, or what combinations of them may be added as supplements to foods or feeds in order to be most readily or completely utilized by the animal. The evidence seems clear that it is possible, through the medium of the plant alone, to balance the mineral nutrients and organic foods necessary for the full development of the animal body. Many soils, however, are so deficient in certain elements that they are not supplied in sufficient quantity to the animal through the plants grown on these soils. The solution of such problems of animal nutrition goes back largely to the soil, where the deficiency may be made up by increasing the supply of nutrients.

Conditions within the digestive tract of the animal must also be given attention. For example, it is well known that the acid or basic reaction of the digestive tract and other factors may affect the absorption or elimination of a mineral salt. Thus the composition of the feed is not the only factor to be considered. This is one reason why recommendations for the use of certain species or varieties of plant to supply this or that element in the diet are subject to change. The fact remains, however, that the value of feeds may be very greatly modified by the conditions under which they are grown in the field. Soil-management practices and the use of fertilizers should be given more critical study from this viewpoint.

WATER IS NOT ENOUGH

The amount of water available to the crop during the various periods of its growth may greatly affect its nutritive value. In general, this is due not simply to the amount of water but to a complex relationship between water supply and available nutrients. Increasing the amount of mineral nutrients if the water supply is deficient, or the water supply if minerals are deficient, is ineffective in improving crop yields.

In general, experimental evidence indicates that there is a greater intake of minerals by the plant when the water content of the soil is relatively high. In the case of nitrogen the actual amount entering the plant is not markedly larger, but the total amount of growth made, especially on a wet-weight basis, is very much greater with an increase in the amount of water. That is, when the water content of the soil is high and nitrogen is available the plants are very much more succulent, but if relatively large quantities of nitrogen are not available, the plants cannot be made to grow vigorously or become succulent no matter how much water is applied.

What is true for nitrogen is also largely true for other essential nutrients. The lack of any particular one becomes noticeable through certain deficiency symptoms which may be fairly well recognized. The fact that water cannot substitute for mineral deficiency should be obvious, but it is frequently lost sight of, particularly in sections where irrigation is practiced. Certain cultural practices may also negate the effect of water supply. These may include excessive pruning of fruit crops, excessive cutting or grazing of field crops, attacks by fungi and insects, and light and temperature conditions.

MANAGING THE TOP OF THE PLANT

In considering the capacity of plants for absorbing and utilizing mineral nutrients, it is a mistake to confine attention exclusively to the soil. The manipulation of the top or aerial portion is also important because it is closely related to food manufacture, or in other words, energy accumulation. It is probable that mineral nutrients are absorbed and accumulated only, or at least mainly, when there is a food reserve within the plant to furnish the necessary energy. If there is no food reserve, then the plant must be directly exposed to light as an energy source. Agricultural practices, therefore, must include those that influence the relation of the top of the plant to the light as well as those that influence its relations to the moisture and nutrients in the soil. Such practices directly affect the green part of the plant where food is manufactured as well as the capacity of the various organs for transportation and storage of food. In brief, if the roots are to function at their best in absorbing and conducting minerals and water for their own development and that of the top, then the top of the plant must make food in quantities sufficient to send at least a portion to the roots. Tillage, fertilization, and irrigation practices can be intelligently performed only when due consideration is given at the same time to the handling of the top. All too often practices applied to the soil have been antagonistic to those applied to the top, and loss instead of gain has resulted.

In the production of forest, field, orchard and garden crops, it is common practice to attempt to control the density of stand. In such practices consideration should be given to the supply of mineral nutrients and moisture available in the soil, and also to the amount of light and the temperature. In a humid region, for example, these practices should be correlated with probable rainfall during any given season, the quantity of light received by the crop during the season, and the shading effect produced by plants growing close together. Many experiments have been conducted to determine the correct density of stand for the most economical production of certain crops, but frequently the data have been interpreted without sufficient reference to records of temperature and sunshine. Recently records of sunshine and temperature have been kept and studied in connection with fertilizer practices for pineapple and sugarcane particularly, but also for other crops. The result has been that fertilizer practices have been changed in many instances, with a saving—as high as 60 percent in some cases—in the amount of fertilizer applied and a marked improvement in the yield and quality of the crop.

In irrigated sections, where the mineral intake of plants can be partly regulated by the amount and time of application of irrigation water, the quantity and quality of the crop may be improved by applying fertilizers at intervals instead of all at once, as is often done. The quantity and type of fertilizer to be used should be correlated with the amount of sunshine and the temperature conditions prevailing during the growth period. With perennial plants this method is particularly useful. Fertilizers may be supplied to fruit trees at the beginning or near the close of the growing season, and the type of growth made by the trees and the quality of the fruit produced may be carefully regulated. In regions where the amount of seasonal rainfall may be depended upon or irrigation water is available, it is often the best practice to supply fertilizers at several times during the growing season. The plant husbandman can judge with great accuracy the type and amount of fertilizer needed by the appearance of the crop or the relative state of its maturity; he can adjust the fertilizer supply to produce a crop of any desired size and quality, giving just enough fertilizer to be completely utilized in conjunction with the carbohydrate and other materials synthesized by the leaves or other green portions of the plant.

FERTILIZERS AND THE CARBOHYDRATE RESERVE

The horticulturist also influences the capacity of plants to synthesize, move, and store carbohydrates by such practices as pruning, spraying, and in some cases—tobacco, for example—shading. The agronomist accomplishes the same end by seasonal cutting, mowing, and pasturage.

It has been suggested above that nitrogen enters into many complex compounds within the plant. As in the case of other mineral nutrients what happens to the nitrogen taken into the plant is conditioned by the available supply of carbohydrates or the opportunity for their synthesis. Indeed, the primary intake of nitrogen, whether as ammonia, nitrate, or some other compound, is profoundly influenced by the conditions of temperature and light—particularly light. Nitrogen applied to the soil as a fertilizer may prove highly toxic to a plant if the carbohydrate content is low. The same concentration of nitrogenous fertilizers applied to plants which have a carbohydrate reserve, or ready opportunity for manufacturing carbohydrates, may cause no injury. In fact, the nitrogen may then enter the plant in large quantities and be utilized in conjunction with the carbohydrates in the formation of compounds used in general metabolism, tissue building, and storage. This has been demonstrated many times in the use of fertilizers on pasture lands, lawns, and truck and field crops.

Nitrogenous fertilizers are sometimes applied to crops—less frequently now than formerly—with the expectation of increasing yields when the concentration in the soil is already too high to be effective. What is frequently needed is less shading or less or more cutting or pruning; in other words, a decrease of any practice that is limiting the capacity of the plants to manufacture, move, or store carbohydrates or similar compounds. To an appreciable degree this is true for other mineral nutrients as well. The fact that in the absence of carbohydrates or carbohydrate synthesis the plant cannot retain or metabolize such nutrients is frequently overlooked or neglected. Because it is so commonly neglected, it is difficult to overemphasize this relationship.

FOUR TYPES OF RELATIONSHIPS

It is worth while to describe here some of the effects of the interrelation of the carbohydrate and nitrogen supplies. This relationship has been observed in greater detail with nitrogen than with most of the other nutritive elements.

In many plants it is possible to establish a graded series of performances under environmental conditions frequently encountered in field or orchard culture. (There are, of course, fluctuations attributable to the influence of other environmental factors that in themselves profoundly affect plant metabolism, including length of day. In some species and varieties, this is of prime importance, counteracting nutrient conditions in the soil, temperature, and even specific growth promoting or inhibiting substances, such as the auxins, hormones, and vitamins.) The four grades of performance here listed are to be considered as rather broad and merging into one another. It is not possible to set up mathematical ratios of carbohydrates to nitrogen content of the plant or to total mineral supply as standards for agricultural practice. The grades or groups are sufficiently well defined, however, to be clearly recognized by plant husbandmen, and they are also characterized by differences in food value and palatability.

TYPE 1—TOO LITTLE CARBOHYDRATE

In group 1 there is an abundant supply of nitrogen, but the supply of carbohydrates or the opportunity for their synthesis is limited. Under such conditions plants tend to be weakly vegetative, growing slowly or not at all, or dying if the carbohydrate restriction is very severe. They are generally succulent, relatively high in water content, and often particularly susceptible to attack by fungus and bacterial diseases. They decay rapidly after death or when turned into the soil. Their relative mineral content is frequently low and they do not furnish large quantities of energy-supplying food for animals. They may be of value as dietary supplements because of their succulence and their content of vitamins or accessory growth factors.

In practice, plants of this character are to be found growing in greater or less dense shade, either as intercrops or shaded by overtopping vegetation or by such structures as buildings, rocks, shade cloths, and the like. Very frequently the same conditions result when crops are subjected to excessive removal of leaves by disease or insects or by extremely heavy pruning, very frequent heavy cutting, or unusually heavy grazing. This is one reason why many pastures die out or greatly decrease in forage value when very heavily grazed for a period of months or years. Sometimes only the more palatable species are severely eaten or cut back. Unable to make sufficient carbohydrates to supply the stem, storage organs, or roots, they grow feebly or die out and are replaced by the less palatable species, which have not been handicapped by so great a reduction in leaf area. This also helps to explain why some species will persist for a longer period in regions of high light intensity and perish where the light intensity is lower.

This does not mean that grazing or cutting may not be advantageous under many circumstances. It is undoubtedly true that many native grasses will die out more quickly if not grazed at all than when subjected to moderate grazing. The old tops, ungrazed, may have a shading and smothering effect and also tie up some of the mineral nutrients, which are more quickly released to the soil under grazing conditions.

TYPE 2—ABUNDANT NITROGEN AND CARBOHYDRATE

In group 2 there is on the one hand an abundant supply of mineral nutrients, moisture, and especially available nitrogen, and on the other, an available carbohydrate reserve which can be drawn upon for the metabolic processes of the plant, or ample opportunity for synthesis of new or additional carbohydrates. Under these circumstances the tendency of many plants is to grow vigorously, with lush green foliage. Some, including the tomato, the potato, and many others, will also produce flowers, but they frequently fail to mature fruit or at most set a few fruits of poor form, flavor, and quality. At the upper limits of this group, where it merges into the one next to it, in which carbohydrate accumulation is still greater, blooming and even fruit setting may take place, but even here there is generally a vigorous condition of vegetativeness.

Growth of this type is common on rich alluvial soils high in nitrogen and other nutrients, and on soils to which nitrogenous fertilizers have been supplied copiously while the plants have been given little or no pruning or only light grazing. The light pruning or grazing reduces an excessive supply of carbohydrates or somewhat restricts the manufacture of new carbohydrates.

Plants in this group are large and succulent with a relatively low dry weight; at the upper limits, they are slightly smaller, increasingly tough, and higher in dry weight. Many leafy or succulent vegetables have their greatest commercial value at this plane of nutrition. Some types of pasturage also can be most profitably maintained at this level, when they will furnish large quantities of succulent food high in nitrogen values. Some forage crops are cut for hay at this stage in their development because they are then relatively higher in nitrogen content and digestibility than later on, when they are more nearly mature and have accumulated greater quantities of crude fiber or related carbohydrate derivatives. Succulent plants, however, are in general relatively low in some of the carbohydrates and fats, and therefore in energy value.

In some localities, where the intensity of light is very high, this vegetative condition is not maintained throughout the growing season, and in the case of perennial trees and shrubs it is temporary, in spite of large quantities of available nitrogen in the soil. This is a common experience on the range lands and in the irrigated valleys of the West and Southwest. As already stated, environmental factors such as day length and temperature may have a greater effect on the character of growth than does the supply of nutrients in the soil. Plants growing at higher altitudes or in northern latitudes respond differently from those at lower elevations or farther south, although the mineral supply may be the same. No one factor operates in the same manner in all types of environment. The whole environmental complex must always be considered as fully as possible.

TYPE 3—ABUNDANT CARBOHYDRATE

In the third group, the carbohydrates or, in some species, fats and fatlike compounds accumulate in excess compared to the nitrogen supply; that is, more carbohydrates are manufactured than are built into the more succulent vegetative portions of the plant, and the excess is not removed. This particular relationship between nitrogenous and carbohydrate or fatty materials is brought about under natural or artificial conditions when the available nitrogen in the soil is limited or when there is increased opportunity for carbohydrate synthesis or accumulation.

This group makes less vegetative growth than group 2. Such vegetative structures as are produced are less succulent; their texture is more firm or tough owing to increased thickness of cell walls and lower water-holding capacity of the cell contents. Accompanying these vegetative characteristics there is increased tendency toward blooming, fruit setting, and maturing of seeds. This is a very desirable condition for many crops grown primarily for their flowers and fruit, and also for many fiber crops. Hay and pasture plants in this condition are often relatively lower in soluble organic nitrogenous fractions and relatively higher in carbohydrates, carbohydrate derivatives, and fats. Their energy value is greater than that of plants in the second group. At its lower limits, plants in this group are very valuable for feed or food because of the reserves of carbohydrate and nitrogenous material they contain. At the upper limits, plants are frequently tough, woody, or relatively high in dry-weight substances and therefore less desirable as food.

TYPE 4—TOO LITTLE NITROGEN

In the fourth group, the supply of nitrogen or other mineral nutrients such as potash or phosphorus is a distinctly limiting factor. The result is that, unless some other restriction is imposed by the environment, the carbohydrates or their derivatives come very greatly to predominate over the nitrogenous or mineral content of the plant. In general the condition is the reverse of that in group 1, though there is a superficial resemblance since in both groups vegetative growth is very greatly reduced. Frequently almost no growth is made. Because of this general resemblance the two conditions have frequently been confused, and measures intended to correct the one have been applied to the other, naturally without success. In addition to slow vegetative growth, plants in this fourth group are characterized by very stiff, hard, woody stems or leaves. Flower production is sometimes profuse, but when the mineral supply is extremely limited the plants fail to bloom as well as to grow. Fruit setting and development are greatly decreased, such few fruits as may mature being of small size, often of somewhat intense but inferior coloration, and poor in quality. Grasses and forage crops grow very sparsely and are often yellowish or grayish in color and tough or wiry and woody. If they have any feeding value, it is as roughage.

The obvious means of correcting this condition is to apply water or mineral nutrients or both to the soil. If small amounts of these are already available, reducing the top through pruning or decreasing the light may bring about a similar response, but less growth is produced and valuable food reserves that could be used for growth and fruiting are removed with the cut material. The fact that many types of plants in this condition will send up a limited quantity of top growth when severely pruned, mowed, or grazed, has led to the erroneous idea, less commonly held than formerly, that the more the tops of plants are cut back the more vigorously they will respond in subsequent growth. Taken at its face value no statement could be farther from the facts. Obviously this method must result in a marked decrease in the total amount of growth on a given area of land.

The conditions prevailing in this fourth group are common over large areas, especially in the older agricultural districts, where crops have been removed from the land without provision for restoring available nitrogen and other nutrients through fertilizers or organic matter. These elements eventually become so decreased that the productive capacity of the soil is greatly reduced.

This discussion applies to many other mineral nutrients as well as nitrogen. Only when a management system establishes a balanced relation between all soil constituents and the treatment given the tops can it be said to be sound. There is no exception to this even in the case of the so-called trace elements that must be present, though sometimes in extremely minute quantity, if the growth of plants is to be maintained at the highest levels.

FIELDS FOR FUTURE RESEARCH

The full significance of the trace elements has been realized only in comparatively recent years. A great deal of investigation is still in progress in this field. Unquestionably some elements not now known to be essential will be found to be so for certain plants or under certain conditions. Much remains to be discovered, too, concerning the relation of some organic compounds, such as the vitamins, to the rate and character of growth on certain soils and in certain environments.

It is especially important at the present time to determine not only the value of all these elements and compounds in their relation to the development of the plant, but also the effect of different environmental conditions on the value of plant products as food or for industrial uses. Progress has been made in determining the effects of the various nutrient elements on the growth and development of plants and the role of these elements in animal nutrition. It is known that plants vary greatly in their composition according to the soil environment, but what the range of this variation may be is far less well understood. Future researches should be concerned with the value of agricultural products, particularly plant products of every kind, from the standpoint of health, disease, and human welfare in general.

It is essential, for instance, to test the value of plants produced under different conditions by feeding them to the usual laboratory animals and making observations on rate of development and all the other factors involved in nutritional well-being. Eventually plants of known composition produced in quantities sufficiently large to note their effect on selected groups of human beings must be tested. The importance from the health standpoint of certain elements, such as iron, cobalt, copper, calcium, phosphorus, and iodine, and such compounds as the vitamins and hormones, is much better understood than formerly, and additional data are being secured fairly rapidly. Previous work has shown the nutritional significance of fats, carbohydrates, and proteins, and of the quality of proteins. Further investigation should bring out the variations in the value of these food materials when they are supplemented with other compounds of dietary importance.

In many studies up to now, a relatively small number of analyses has been made to determine specific elements in foods in relation to the geographic source of the food. The soil type on which the plant was grown or the climatic conditions to which it was subjected are generally not known. There should be a concerted attempt to correlate composition of foods with soil type, climatic conditions, and cultural practices, including the use of fertilizers. That the same foods grown in different localities may show wide variation in content of nutritionally important elements is well illustrated in the cases of iodine, copper, cobalt, and others. Harmful effects have been demonstrated in the case of selenium.

The importance of these trace elements in foods and the need to secure them through food plants grown on soils containing them or enriched with fertilizers of which they form a part are now fairly well recognized. The effects on animals of deficiencies in phosphorus and calcium in feed produced on deficient soils are well known. The occurrence of the same difficulties has been reported from many sections throughout the world, and there is no reason to believe that similar conditions of deficiency for other elements are not widespread. An inventory should be made of the minor or trace elements in various soil areas and types to determine where these constituents occur in abnormally low, normal, or abnormally high amounts. It is certain that it is possible to correct some of the deficiencies and excesses. A further fundamental study of the physiological effect upon plants and animals of the absence of these minor elements or their presence in varying amounts, and their influence on the elaboration of vitamins and other organic compounds, remains largely still to be made.

The fact that, in addition to those elements whose presence in food is a vital necessity, certain elements used in combating plant pests may be taken up from the foliage or the soil by the growing plants or found in solution in water supplies, is in urgent need of investigation. Such substances may modify the composition of plants so that they become definitely toxic to men or animals consuming them. This toxicity has been demonstrated conclusively in the case of fluorine in water and of selenium in plants. Other substances just as definitely increase the value of the food products to which they are applied and are in no sense toxic. The recent finding that the juice of oranges varies greatly in its nitrogen-phosphorus ratio and that this may furnish a single convenient figure indicating whether nitrogen or phosphorus is the factor limiting yield is of interest.

In popular literature at least, attempts have been made to show that the form in which fertilizer elements are applied, whether organic, inorganic, or colloidal, results in very great differences not only in yield of crop, but in the resistance of plants to disease and insect pests. It is stated that the effects likewise are carried over to men or to animals consuming the crops. Great benefits to health are claimed under some circumstances. All this should be put to rigorous test. These studies should involve an evaluation of the composition, reaction, moisture supply, temperature, physical character, and biology of the soil, and the effects of cultural practices, fertilization, and prior vegetation, on the ability of plants to accumulate, utilize, or modify soil constituents. The extent to which these differences may be passed on in the plants consumed as food is yet to be fully determined. It may be quite possible to incorporate optimal quantities of essential elements in meat, dairy, and poultry products by way of the soil.

The fact that such factors as light intensity, length of day, temperature, and humidity greatly modify and in large part determine the character of growth of plants has already been emphasized. How to distinguish these factors, as well as inherent varietal differences in plants, from the effects due primarily to soil factors has not yet received the attention it merits. The scientific literature abounds with examples of differences in the chemical composition of plants and plant parts resulting from differences in fertilizers, day length, temperature, and perhaps other factors. Only a beginning has been made in following up these findings with actual feeding tests to show what they mean from a nutritional standpoint.

THE DIGESTIVE PROCESSES IN DOMESTIC ANIMALS

by H. W. Schoening[1]

THE processes by which different food materials from the outside world are taken into the animal body and made ready for use are complex and wonderful. This article tells the story of digestion in cattle, sheep, pigs, horses, dogs, cats, and fowl in as much detail as is possible in a short space. It gives a background for the articles that follow on the nutritional requirements of animals and feeding practices.

NEARLY all food materials are in too complex and insoluble forms as they are consumed by either animals or man to be absorbed and assimilated. The specific purpose of digestion, therefore, is to convert these food substances into simple and soluble materials fit for absorption and assimilation. All animals except the most primitive types are provided with several highly specialized digestive organs.

The digestive tract may be described as a tube extending from the lips to the anus, constructed with such dilations and constrictions throughout its length as to form a number of compartments, each of which has a specific function in the digestive process. The contents of the tube, that is, the foods taken in, or ingested, by the animal, are propelled by wavelike movements known as peristalsis. In addition to moving the food along the tract until it is eventually expelled, the movements serve to mix the food with the digestive juices, to promote absorption of digested material, and to enhance the flow of blood and lymph through the intestinal vessels.

The degree to which this system has been elaborated in the several species under consideration suggests the kind and character of food usually eaten. The kind of foods habitually used brings each species of animal under one of three classifications: Carnivorous (meat-eating), herbivorous (plant-eating), or omnivorous (eating both meat and plant substances). Of the herbivorous species, the horse, ox, and sheep are the most important among domesticated animals; the dog and cat exemplify the carnivorous; and the pig and the barnyard fowl are representative of the omnivorous type.

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It is quite obvious that the herbivorous animal needs a different kind of digestive apparatus from that of the carnivorous animal, while the omnivorous one naturally needs a set of digestive organs adaptable in some degree to either type of diet. These differences involve the method of acquiring food as well as of preparing it for digestion and of actually digesting it.

If the finding and selection of food are considered as essential preliminaries to the digestive process, it would seem proper to enumerate the senses of sight, smell, touch, and, in the case of predatory animals, hearing also as preparatory functions preceding the intake of food. The powers of sight and scent are useful to all animals in finding their food. In the case of the horse, the sensitive nerve structures of the upper lip assist the animal to discern by the sense of touch the presence of edible food substances.

Strictly speaking, however, the digestive process begins with the prehension, or taking up of food; continues with its mastication (chewing), insalivation (mixing with the salivary secretions), deglutition (swallowing), and the digestion, absorption, and assimilation of those food elements that are of nutritive value; and terminates with defecation, or the excretion of the remaining ingested matter not capable of being absorbed or utilized as nourishment. To perform these functions, the digestive tract of the animal is equipped with mouth, teeth, tongue, pharynx, esophagus, stomach, intestine, and anus. Even among the various common domestic species, differences exist in certain portions of the digestive tract to accommodate the special requirements of the species.

TAKING OF FOOD

Prehension, or the taking up of food, is accomplished in most animals by means of the lips, teeth, and tongue. In the horse, prehension is performed by the strong and flexible upper lip and incisor teeth (fig. 1). When grazing, this animal employs lips and incisor teeth, cutting or tearing the vegetation seized by jerking movements of the head or neck. The ox is not endowed with such mobile lips or with upper incisor teeth (fig. 2). Instead it uses its long, muscular tongue to pull the grass or hay into its mouth, cutting it off between the lower incisors and the upper gum by an upward movement of the head and neck. The sheep seizes its food in much the same manner, but it makes use of its mobile lips rather than its tongue in gathering food into the mouth. The native habit of the pig of burrowing or rooting to find its food has survived the domestication of this species. Prehension, however, is accomplished by the movements of the pointed lower lip and is assisted by the teeth and tongue (fig. 3). In the dog (fig. 4) and the cat, the food is seized by the incisor and canine teeth and brought into the mouth by jerking movements of the head and jaws. The organ of prehension in fowls is the beak. The fowl picks up its food in its toothless beak and passes it to the base of the tongue preparatory to swallowing.

Drinking is accomplished by the horse, ox, sheep, and pig by sucking the fluid into the mouth by the aid of the tongue and pharynx. The lips form a small opening which is dipped beneath the surface of the water, and the tongue moving back and forth like a piston in a cylinder creates a negative pressure in the mouth which causes water to pass into the mouth with the backward thrust of the tongue and to be swallowed with the forward thrust. The pharynx serves as a valve in this pumping process. The dog and the cat take up liquids by lapping with the tongue. In the fowl, drinking consists merely of

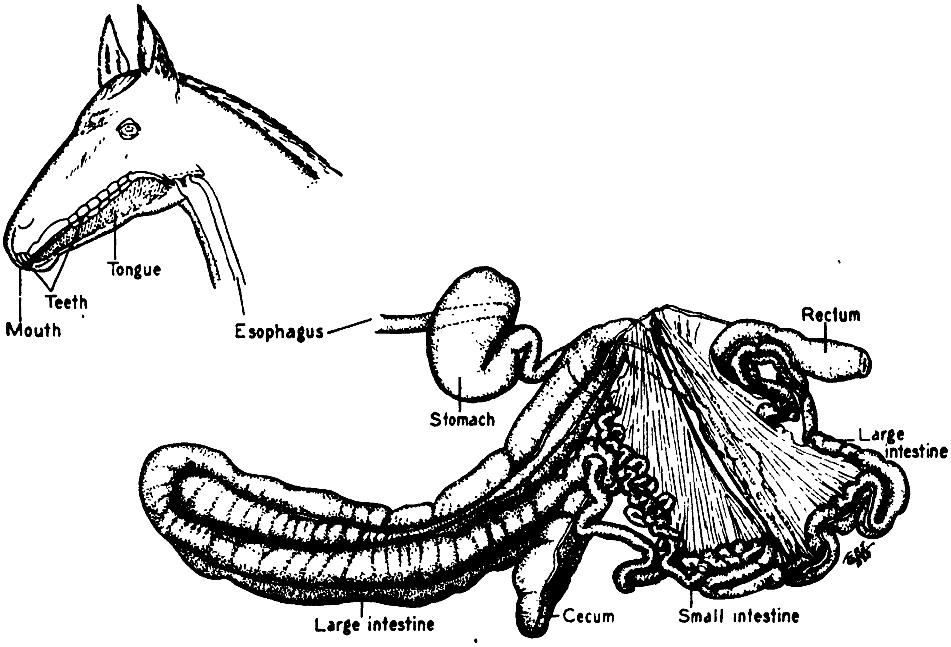

Figure 1.—The mature horse has 6 incisors in upper and lower jaw and 6 molars on each side, upper and lower. The male horse has 2 canines in upper and lower jaw. The mare has no canines. Total for horse, 40 teeth; total for mare, 36 teeth. (After F. Smith, A Manual of Veterinary Physiology.) Capacity of stomach, 4.75 gallons; of small intestine, 16.86 gallons; of cecum, 8.8 gallons; of large intestine, 25.36 gallons. The small intestine is about 73.6 feet long. The cecum is 40 inches long. The large intestine is approximately 21.22 feet long. (Intestinal proportions after H. H. Dukes, The Physiology of Domestic Animals.)

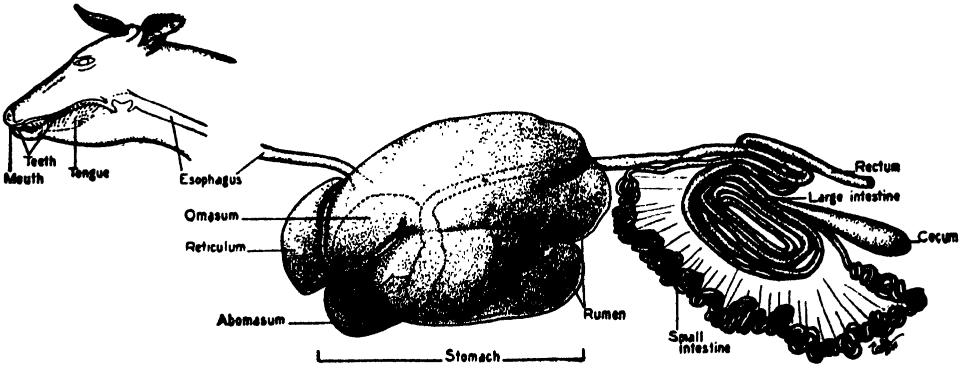

Figure 2.—The ox has 8 incisors in the lower jaw and no upper incisors. This species has 6 molars on each side in the lower and upper jaws. It has no canines. Total, 32 teeth. (Smith.) Capacity of stomach, 66.71 gallons; of small intestine, 17.43 gallons; of cecum, 2.6 gallons; of large intestine, 7.4 gallons. Length of small intestine, 150.88 feet; of cecum, 2.89 feet; of large intestine, 33.3 feet. (Dukes.)

scooping up the fluid into the lower beak and then elevating the head to permit it to flow by gravitation into the crop or stomach. The pigeon's method of drinking, however, more nearly resembles that of the horse or ox than that of other birds. This bird thrusts its beak deep into the water and by a very rapid movement of the tongue sucks in the liquid.

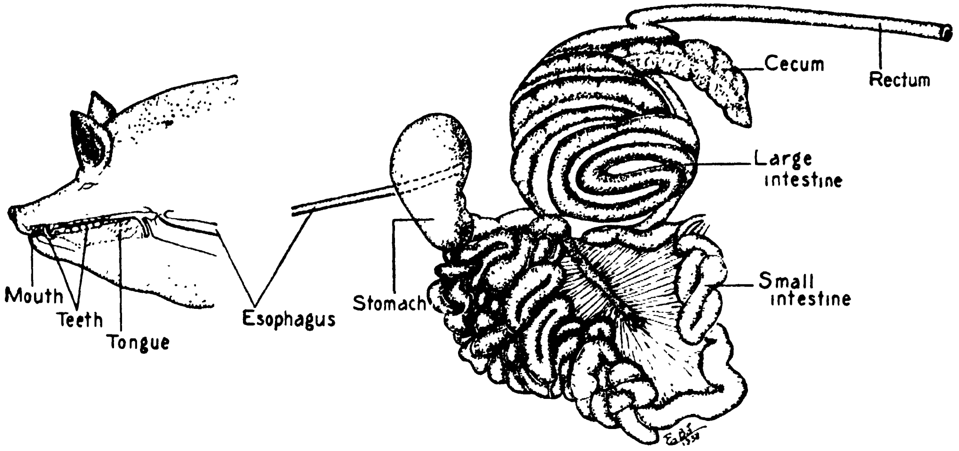

Figure 3.—The pig has 6 incisors, upper and lower; 2 canines, upper and lower; 7 molars on each side, upper and lower. Total, 44 teeth. (Smith.) Capacity of stomach, 2.11 gallons; of small intestine, 2.43 gallons; of cecum, 0.31 gallon; of large intestine, 2.3 gallons. Length of small intestine, 60 feet; of cecum, 9.05 inches; of large intestine, 16.4 feet. (Dukes.)

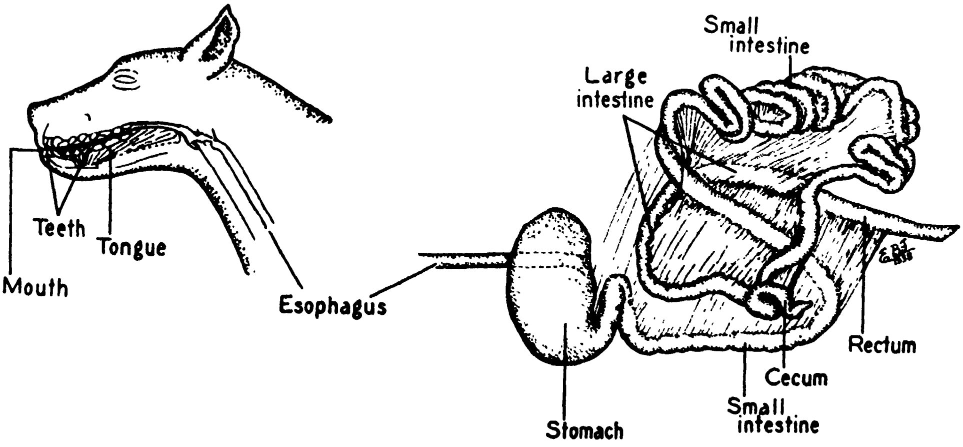

Figure 4.—The dog has 6 incisors, upper and lower; 2 canines, upper and lower; 6 molars in each side of the upper jaw, 7 molars in each side of the lower jaw. Total, 42 teeth. (Smith.) Capacity of stomach, 1.14 gallons; of small intestine, 1.7 quarts; of cecum 1.5 fluid ounces; of large intestine, 15.36 fluid ounces. Length of small intestine, 13.67 feet; of cecum, 3.12 inches; of large intestine, 1.97 feet. (Dukes.) (The figures for size and capacity of the internal organs are average; they would of course vary with the size of the animal.)

CHEWING

After the prehension of food, the next step, except of course in the toothless fowl, is mastication. Mastication, or chewing, of food is accomplished by means of grinding teeth so situated in the upper and lower jaws that they can be employed to crush and divide the food substance preparatory to swallowing. The mechanism of mastication involves the use of the two jaws, the tongue, and the cheeks. The upper jaw is a rigid portion of the head, while the lower jaw is hinged to the skull so that it can be moved in a vertical and to some extent in a lateral or diagonal plane against the upper jaw. These movements are brought about by the muscles of the jaws. There is a pronounced sidewise or lateral movement of the lower jaw in the ruminants (ox and sheep), slightly less in the horse, and still less in the omnivorous pig. In the carnivores (dog and cat), there is very little lateral movement.

Striking differences exist in the chewing structures of the various species, particularly as to the kind of teeth and their functions. Some animals have three kinds of teeth and others two kinds. The front or incisor teeth, which occur in all mammals, are used for detaching or cutting the food into suitable proportions for chewing. These teeth are in both the upper and lower jaws except in ruminants, in which the upper incisors are lacking. Ruminants, however, have a tough upper gum known as a dental pad, against which the lower incisors compress the forage in cutting or tearing it off. The canine teeth or tusks function both for seizing food and for combative purposes.

The masticatory teeth, or molars, which are common to all species, are located laterally in both upper and lower jaws. Food material brought between the opposing rows of teeth by the movements of the cheeks and tongue are comminuted, or reduced to fine particles, by the crushing or grinding movements of upper and lower molars as they are brought together during the chewing process. In the horse, ox, and sheep, the grinding surface of the molars slopes sidewise, those of the upper jaw presenting an acute angle on the outer side and those of the lower jaw being pointed on the inner side. In the pig, dog, and cat, the grinding surface is more nearly at right angles to the long axis of the tooth.

Mastication in the horse, pig, dog, and cat is a single process preparatory to swallowing. The dog and cat chew very little, usually bolting their food in relatively large pieces.

In the ruminants, represented by the ox and sheep, this process is divided into two phases: (1) Preliminary or incomplete mastication when the food is first taken, and (2) complete mastication, which is postponed for more leisurely performance. The ruminant is unique among animals in being equipped with a partitioned stomach consisting of four compartments (fig. 2). These are known as the rumen, paunch, or first stomach; the reticulum, honeycomb, or second stomach; the omasum, manyplies, or third stomach; and the abomasum or rennet, the true or fourth stomach. The food material, which is usually of a coarse nature, after being partly chewed enters the paunch or rumen, from which it is later regurgitated or returned to the mouth and rechewed in individual boluses during repose. This process of rechewing is known as rumination. Each bolus of food brought up for rumination is chewed for somewhat less than a minute. Grains form a part of the bolus only to the limited extent that they are accidentally caught in the roughage. Consequently, all unchewed grain passes through the animal and appears in the feces in an intact condition. In cattle a certain quantity of whole grain is not crushed during eating and rumination, and on this account grain is commonly ground for cattle. This is rarely done for sheep, which chew most grains very thoroughly. In ruminants the mucous membrane lining the cavity of the mouth is thicker than that of the horse and is furnished with many horny protuberances, known as papillae, which facilitate the manipulation of food during mastication.

The exceptionally mobile tongue of the ox has a groove across the upper surface a few inches back of its tip. This groove is frequently the seat of injury caused by sharp spines, awns, etc., in forage eaten by cattle. The injury is not a simple wound, and in most cases it results in the formation of a chronic ulcer with slight tendency to heal. Although many types of the common wound-infection micro-organisms are found in the lesion, actinobacilli and actinomyces fungi are most often encountered and certainly cause the most damage. The latter organisms are responsible for the so-called "wooden tongue" of cattle. Because of this peculiar anatomy of the cow's tongue with its susceptibility to injury, care should be exercised to exclude from the feed as much as possible all sharp, spiny substances.

THE SALIVARY SECRETION AND SWALLOWING

Mastication and the presence of food in the mouth cavity stimulate the secretion of saliva in the mouth in all mammals. In man the principal constituent of this secretion is a substance known as ptyalin, or salivary amylase, which functions in the digestion of starchy substances, but of the domestic animals only the pig possesses enough ptyalin in its saliva to be of importance in digestion. The salivary secretion in most domestic animals serves mainly to lubricate the food for swallowing. In ruminants the presence of saliva in the paunch assists in the regurgitation of partially masticated food for rechewing. In digestion by ptyalin or salivary amylase, the starch is first changed to soluble starch and finally to maltose.

Deglutition is the act of swallowing the food that has been taken into the mouth. It is accomplished by a series of muscular movements involving principally forcing the food to the rear of the mouth cavity by elevation of the fore part of the tongue and depression of the root of the tongue, followed by the dilatation of the pharynx. The bolus then passes through the pharynx and esophagus into the stomach. The initial phase of the act of deglutition, that relating to its passage into the esophagus, is entirely a voluntary process, but the completion of the act is involuntary.

The quantity of food material that can be swallowed at one time is comparatively small in the horse on account of the narrow lumen, or space between the walls of the pharynx and the esophagus. A much larger bolus can be swallowed by the ox, whose deglutitive organs are of more ample proportions. Nevertheless, ruminants frequently choke on apples, beets, turnips, and other pieces of food that have not been chopped fine enough for ready swallowing with little chewing.

There is no special or unusual factor involved in the swallowing process on the part of the pig, dog, cat, or fowl.

Fluids are swallowed in much the same way as solids, except that they are passed into the esophagus and stomach with extreme facility and rapidity as compared with solid boluses.

DIGESTION

In general the processes of gastric digestion are similar for all domestic animals. In the horse, pig, dog, and cat, the food material passes into the stomach as soon as it is swallowed and is there brought into immediate contact with the digestive fluids of the stomach—principally pepsin and hydrochloric acid. The fluids are mixed with the food by churning movements of the organ.

The action of bacteria upon food taken into the stomach of the horse, pig, or dog is short-lived owing to the rapid production of hydrochloric acid there. In the ox and other ruminants, however, considerable bacterial action is exerted upon the enormous amount of material taken into the capacious rumen prior to its regurgitation, remastication, and digestion. This bacterial action is favored by the slightly alkaline reaction of that portion of the stomach and its freedom from gastric secretions, as well as by the prolonged sojourn of food matter therein. The changes brought about by bacteria inhabiting the alimentary tract include the breaking up of cellulose and fats, the production of organic acids such as acetic, butyric, and lactic, and the splitting of the carbohydrates known as polysaccharides. The gases, methane, carbon dioxide, hydrogen, etc., are formed during bacterial action in the rumen, but they are of no value to the animal and are excreted as waste.

The first three stomachs of the ruminant are essentially for the purpose of storing and grinding the food material, true digestion taking place largely in the fourth stomach (the abomasum), and finally in the intestine.

The stomach of the horse is comparatively small. According to Dukes (*285*)[2]—

> it has been estimated that a horse may swallow during a given meal two or three times the amount of material (food and saliva) remaining in the stomach at the close of the meal. The excess, together with the food remaining from the previous meal, must pass on into the intestine during the meal, the first food consumed being in general the first to pass out. This consideration means that a good deal of the food cannot remain long in the stomach and raises the question of the importance of stomach digestion in the horse.

The true stomach of the ox or sheep is also comparatively small and receives food gradually in a well-macerated or ground-up condition from the first three stomachs. The stomach of the pig, dog, or cat is sufficient in size to contain all the food that may be consumed at a meal, and food may be retained in the stomach for a considerable time. In all mammals the food is mixed and softened in the stomach by muscular movements, assisted by the action of the gastric juice. The softer portions of the food material thus prepared are then passed into the intestine, but food not ready for intestinal digestion is not allowed to pass from the stomach, with the exception of whole grain in cattle.

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[2] Italic numbers in parentheses refer to Literature Cited, p. 1075.

Fowl, having no teeth, must swallow their food whole or at best only coarsely broken by the beak at prehension. Such material passes through the pharynx and esophagus into the crop (fig. 5), which in most avian species is nothing more than a dilated portion of the esophagus. The purpose of the crop of the fowl, like that of the rumen of the ox and sheep, is largely bulk storage of food. This material then passes by slower stages into the proventriculus, or glandular stomach, a specialized gastric organ of small capacity whose wall is furnished with secretory glands supplying pepsin and hydrochloric acid. The food material after coming into contact with these digestive fluids continues on its way into the gizzard, or muscular stomach. That organ is lined with a tough membrane and is so constituted that it retains a certain portion of the grit normally swallowed by the fowl. The food substance is somewhat softened by the time it reaches the gizzard, where it is subjected to crushing contractile movements stimulated by the presence of food. The food substance is reduced to a very fine consistency by the rubbing together of the grit and the tough, corrugated lining of the organ. This process corresponds to mastication. Strictly speaking, there is no true gastric digestion in the fowl, such as is common to mammals. The food material after being finely divided in the gizzard is passed on into the first portion of the small intestine, where it is more thoroughly mixed with and digested by the juices derived from the proventriculus as well as the other digestive enzymes emptying into the intestine.

The alimentary tract of the chicken is for the most part representative of those of the majority of species of domesticated fowl, but there are some minor differences.

The pigeon is peculiar in not possessing a gall bladder, and in having ceca that are small and poorly developed as compared with those of the duck and chicken. Neither the duck nor the pigeon possesses a true crop comparable to that of the chicken, but in these species there is a specialized enlargement of the esophagus which serves the purposes of the crop. The small intestine of the pigeon is shorter in proportion to the size of the bird than that of the duck or the chicken.

The pigeon is also peculiar in being specially equipped to nourish its young by regurgitating into the mouth of the squab a milklike substance secreted in the "crop." The mechanism by which this substance is secreted is as follows: Beginning about the eighth day of incubation of the eggs, the cells of the mucous membrane of the crop in both the female and the male birds increase in size and number. These cells, which contain considerable quantities of fat, secrete fat globules into the crop during the course of incubation in much the same manner as the cells of the mammary glands of mammals act in the secretion of milk. There is also a constant shedding of these cells, which then form a part of the milklike substance. At the time of hatching of the eggs, an abundance of "pigeon milk" is ready for feeding the squabs. The secretion of the milk continues until about the twentieth day after hatching.

The following composition has been determined for this curious lacteal secretion: Dry matter, 14 to 25 percent; fat, 25 to 29 percent; protein, 13 to 14.5 percent; calcium, potassium, magnesium, and phosphorus (in the ash); no sugar; enzymes; amylase; and saccharase.

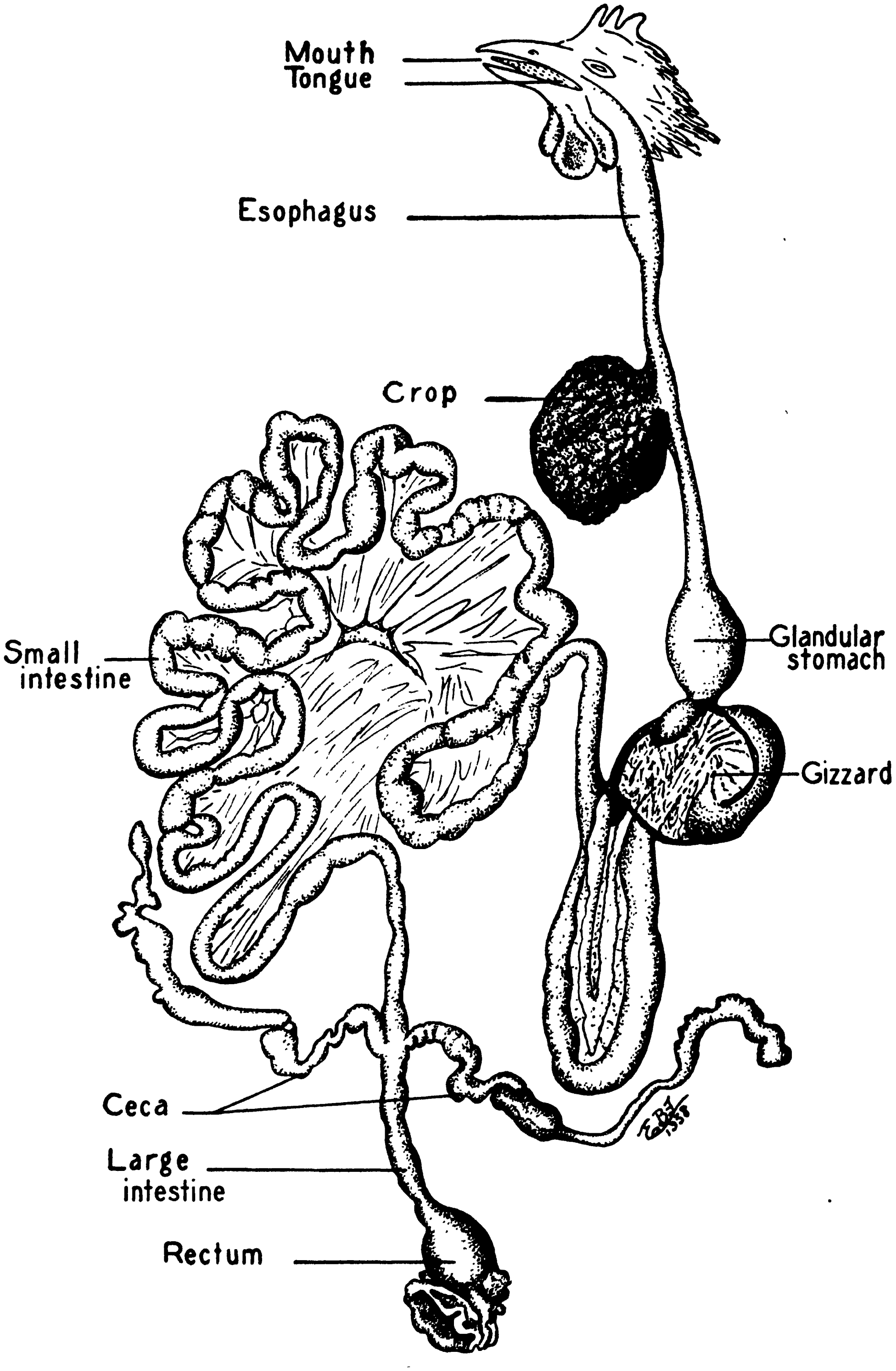

Figure 5.—The digestive tract of the fowl (after B. F. Kaupp, The Anatomy of the Domestic Fowl). Capacity of gizzard, 0.089 pound. Length of proventriculus, 1.62 inches; diameter of glandular stomach (proventriculus), 0.8 inch. Length of small intestine, 61.7 inches; of ceca, 7.6 inches each; of large intestine, 4.6 inches.

The striking features of pigeon milk are its high fat and protein content and the absence of sugar. In this respect it resembles the milk of the rabbit. Young rabbits stand out as having the most rapid rate of growth among mammals, and the pigeon holds the record among birds for rapidity of growth during the first 20 days after hatching. The squab doubles its weight within 48 hours after hatching, while the duck requires 6 days and the chicken 9 days. In 20 days from hatching, a squab has shown an increase in weight from 20 to 435 grams.

There is evidence that a hormone, prolactin, an internal secretion of the anterior pituitary gland located at the base of the brain, is the inciting agent of pigeon milk. Injection of prolactin into pigeons produces the effect described in the membrane lining of the crop. Moreover, the injection of this substance into castrated male pigeons 6 months after castration engendered a secretion in the crop.

Sometimes the death of the squabs and the consequent failure to use the secreted material results in a congestion of the crops of the parent pigeons. Such a condition is best overcome by furnishing another squab for the pair to nurse.

In the horse, ox, sheep, and pig, well-ground and softened food in the stomach undergoes gastric digestion through the action of the pepsin and hydrochloric acid of the gastric juice. In the dog and cat, in which mastication has been eliminated to a large extent, the food in the stomach is subjected to the same process as in the other animals but for a longer period.

Digestion by the gastric juice is essentially the same in all animals (fig. 6). The pepsin of the gastric juice in the presence of hydrochloric acid acts upon proteins of either animal or vegetable origin and converts native protein into the simpler products, proteoses and peptone. The latter substances are not yet ready for absorption but require further conversion into amino acids. This step in protein digestion remains to be completed in the intestine.

Another digestive enzyme sometimes known as rennin is present in the gastric juice of young mammals. This enzyme coagulates milk so that the casein is prevented from too rapid passage through the stomach and the pepsin is enabled to convert it into proteoses and peptone. In all species, following gastric digestion the semiliquid substance is passed into the small intestine; at this point it is known as chyme. Digestion by pepsin occurs largely in the stomach, but it is continued to some extent in the first part of the small intestine.

In the intestines the chyme undergoes further digestion by the action of pancreatic juice, intestinal juice, and bile. The pancreatic juice contains three important enzymes—trypsin, steapsin, and amylopsin. To a limited extent trypsin, like pepsin, converts native protein into proteoses and peptone. Principally, however, it continues the digestion of protein where the pepsin leaves off, that is, breaks the proteoses and peptones into the amino acids, which can be absorbed. The steapsin breaks down or hydrolyzes fats into fatty acids and glycerol, in which forms they are ready for absorption. Some of the fatty acids resulting from steapsin digestion combine with the available alkali in the intestinal juice to form soaps which assist in emulsifying any remaining undigested fat. The amylopsin

FOOD	ENZYME	SECRETING GLAND OR ORGAN	STEPS IN THE BREAK-DOWN
STARCH	PTYALIN OR SALIVARY AMYLASE[1]	SALIVARY	STARCH SOLUBLE STARCH ERYTHRODEXTRIN MALTOSE ACHROODEXTRIN MALTOSE MALTOSE
STARCH	AMYLOPSIN OR PANCREATIC AMYLASE	PANCREAS	SAME AS FOR PTYALIN
MALTOSE	MALTASE	INTESTINE	MALTOSE GLUCOSE
SUCROSE	SUCRASE	INTESTINE	SUCROSE GLUCOSE FRUCTOSE
LACTOSE	LACTASE	INTESTINE	LACTOSE GALACTOSE GLUCOSE
PROTEIN	PEPSIN (+HYDROCHLORIC ACID)	STOMACH	PROTEIN ACID-META-PROTEIN PROTEOSE PEPTONE
PROTEIN (MILK)	RENNIN	STOMACH	CASEIN PARACASEIN (+CALCIUM) MILK CLOT
PROTEIN	TRYPSIN	PANCREAS	PROTEIN PROTEOSE PEPTONE-AMINO ACIDS
PROTEIN	ENTEROKINASE	INTESTINE	ACTIVATES TRYPSIN
PROTEIN	EREPSIN	INTESTINE	PEPTONES AND PEPTIDE AMINO ACIDS
NUCLEOPROTEINS	NUCLEINASE	INTESTINE	DIPEPTIDS AMINO ACIDS
FATS AND LIPIDS	LIPASE[2] (STEAPSIN)	PANCREAS	FAT FATTY ACIDS AND GLYCEROL
FATS AND LIPIDS	LIPASE	INTESTINE	SAME AS PANCREATIC LIPASE

[1] ONLY THE PIG, DOG, AND CAT HAVE THE SALIVARY AMYLASE.

[2] THE PANCREATIC LIPASE IS MOST IMPORTANT, THE GASTRIC LIPASE BEING OF LITTLE PHYSIOLOGICAL IMPORTANCE.

Figure 6.—The break-down of various food elements in the digestive system and the enzymes involved.

converts or hydrolyzes starch and the dextrines into maltose. Maltose requires further breaking up by other digestive juice before it is ready for absorption.

The intestinal juice contains a number of digestive enzymes, for example, enterokinase, erepsin, maltase, sucrase, lactase, lipase, amylase, and nucleinase. Enterokinase is largely concerned in the activation of the enzyme trypsin of the pancreatic juice. Erepsin, which is a proteolytic enzyme—that is, one that has the power to break down proteins into simpler diffusible substances—converts peptones and peptids into amino acids. Maltase converts the maltose resulting from the action of amylopsin on starch into glucose, in which form it can be absorbed. Sucrase breaks down or hydrolyzes sucrose into glucose and fructose, in which forms they are assimilated. Lactase, which is present only in young mammals ingesting milk, converts lactose (milk sugar) into glucose and galactose. This enzyme is lacking in mature animals that do not consume milk as food. However, it is reported that lactase can be made to recur in adult animals fed milk or lactose. Lipase is the same as steapsin and converts fats into fatty acids and glycerol. Amylase hydrolyzes starch. Nucleinase converts nucleoproteins into protein and nucleic acid.

Bile is a highly complex fluid formed in the liver. It is not an enzyme but plays an important role in the digestion of fats. The flow of bile into the intestinal tract is more or less continuous, but it increases after the entrance of food into the stomach. Its quantity is governed by the amount and character of the food received. The elaboration and storage of bile in the liver and its release into the intestinal tract are not the only or the most important duties of the liver, but the other functions of that organ have no place in this discussion. The principal constituents of bile are bile pigments, bile salts, and cholesterol. The bile salts only are concerned in the digestive process. They aid digestion by activating the pancreatic lipase, enhancing the action of pancreatic amylase, emulsifying fats, and increasing the solubility of fatty acids and their soaps so that they may be ready for absorption. Bile also is necessary for the absorption of the fat-soluble vitamins. Bile being a reservoir of alkali helps to maintain the alkaline reaction so necessary for pancreatic intestinal digestion.

In addition to the enzymes secreted by the various organs, there are, particularly in the digestive tracts of herbivores and omnivores, bacteria which break down cellulose into substances that can be absorbed and used by the animal organism. This bacterial activity is of considerable importance, since the vegetable substance consumed in large quantities by the horse, ox, sheep, and pig contains a large proportion of cellulose, which is not digested by the enzymes in the various digestive juices. This bacterial digestion makes available for utilization by the body large quantities of otherwise indigestible food material.

ABSORPTION

The digestive processes by which carbohydrates and fats are broken down into soluble or emulsified forms ready for absorption have been described. The inorganic salts, water, and vitamins contained in food require no breaking down but are absorbed as such. The end products of protein digestion are amino acids. Carbohydrates are broken into simple sugars (monosaccharides), principally glucose. The end products of cellulose digestion are probably the simple fatty acids (acetic and butyric) and glucose. The fats are broken down into fatty acids and glycerol. The absorption of all of these food elements occurs chiefly in the small intestine, though some absorption occurs in the large intestine also, particularly in the horse.

The principal avenues of absorption of food are the myriads of microscopic protuberances from the mucosa, or lining membrane of the intestinal wall, known as villi. These minute, fingerlike structures are composed of an outer layer of absorbent cells, a wall containing many blood vessels, and in the center a lacteal or lymphatic vessel. Being in constant contact with the food in a digested state, the villi take up the digested fats and pass them through the lymph channels (commonly known as lacteals) into the blood stream. The lymph within the lacteals is a milky substance heavily laden with the digested fat and is known as chyle. The end products of protein and carbohydrate digestion, inorganic salts, water, and vitamins enter the blood vessels of the villi direct and are transported through the liver into the blood system of the body. These absorbed food substances are carried to the body tissues, where after having undergone complex metabolic processes they are utilized for growth, repair, and energy.

After the digestive tract has taken from the food all the nutritive elements of value to the animal, the remaining material is excreted as waste (feces).

FACTORS AFFECTING MAINTENANCE NUTRITION, FEED UTILIZATION, AND HEALTH OF FARM ANIMALS

by Louis L. Madsen[1]

THE first need of an animal is for sufficient food to maintain its body in good health. Then additional food must be given for production, whether the production is in the form of work or of some product such as meat or milk. Failing to supply fundamental maintenance requirements may seriously, perhaps permanently, injure the animal. Much thought and some research have been given to the question, and this article deals with the problem rather thoroughly, discussing overfeeding as well as underfeeding. Some technical material is included in the article.

THROUGHOUT the entire life span of all animals, whether they are young and growing, mature or aged, producing or not producing, working or resting, healthy or diseased, there is a continual need for food to support the vital functions of the body. The minimum amount of the various foods required to sustain the essential body processes at an optimum rate without gain or loss in body weight or change in body composition, exclusive of the food used in growth or expended in work or other productive functions, is called the maintenance requirement; and a ration which meets only the demands of maintenance is called a maintenance ration. To be ideal a maintenance ration must contain all the necessary nutrients in the proper amounts so that there is neither an excess nor a deficiency of any factor. If such a perfectly balanced ration is fed to an idle animal that is not growing nor yielding any product there would soon be an even balance between the food eaten and the materials lost from the body as body heat and excretions.

These definitions of the maintenance requirement and the maintenance ration refer to ideal conditions which are approached only during careful experimental studies. Values thus obtained serve as the minimum basal requirement of animals and provide control data to which must be added sufficient food to satisfy the additional factors incident to normal activity. The Conference on Energy Metabolism,[2] which met under the auspices of the National Research Council to consider the status of energy metabolism and its place in the development of animal nutrition, recommended for tentative adoption the term "physiologic maintenance" to refer to the requirement of an animal under specified experimental conditions, and the term "economic maintenance" to include the additional requirements for muscular activity found under particular conditions of general feeding practice. Economic maintenance may be more literally expressed as "practical maintenance."

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[1] Louis L. Madsen is Nutritionist, Bureau of Animal Industry.

[2] NATIONAL RESEARCH COUNCIL, COMMITTEE ON ANIMAL NUTRITION. REPORT OF THE CONFERENCE ON ENERGY METABOLISM HELD AT STATE COLLEGE, PA., JUNE 14-15, 1935 ... 93 pp. 1935. [Mimeographed.]

Growing and producing animals need food in addition to their maintenance requirement or their bodies will not be sustained intact. This is because a portion of the food supplied for maintenance will be utilized and even some of the body tissues themselves will be broken down in an attempt to provide for growth and production. Such a process cannot continue indefinitely without seriously interfering with the growth and development of the animal body or reducing its productive capacity. It is evident therefore, that growth, development, and economical production by farm animals depend upon (1) adequate food to maintain the vital functions, or internal work, of the body, plus normal activity, and (2) sufficient additional food to fulfill the demands for growth and production.

Cash returns above feed cost are the primary source of income in the livestock industry, and economy of production by animals depends upon how much food is consumed above that required for maintenance and how efficiently it is utilized and converted into products. Before any continued yield of products can be obtained or physical work performed by animals it is necessary that their maintenance nutrition be adequate. If an animal is forced to labor when existing on a maintenance or submaintenance level of food intake, wasting of body tissues will occur and working efficiency will steadily decrease. A good dairy cow will not stop secreting milk as soon as the ration becomes inadequate to sustain optimum production. Milk production will continue for a time, but at a decreasing rate and at considerable expense to the body tissues, and before it stops entirely considerable damage and possibly permanent injury may result.

Uneconomical production by farm animals is not the only result of a failure to supply them with adequate food for maintenance and production. Other serious losses result from the so-called nutritional deficiency diseases, which not only may impair the development and producing capacity of animals but may be so severe as to cause death. Disease resulting from nutritional deficiencies may be mistaken for or complicated by the presence of certain parasitic and infectious diseases. In fact, animals suffering from the lack of one or several essential nutrients may lose their ability to withstand infection and will be overcome through the combined effects of malnutrition and disease.

Henry Prentiss Armsby (1853–1921), an expert in animal nutrition for the United States Department of Agriculture and first director of the Institute of Animal Nutrition of the Pennsylvania State College, was one of the first American investigators to emphasize the importance of the maintenance requirements in the nutrition of farm animals. He wrote (*32*): [3]

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[3] Italic numbers in parentheses refer to Literature Cited, p. 1075.

A very considerable fraction of the feed actually consumed by farm animals—on the average probably fully one-half—is required simply for maintenance. But if half of the farmer's feed bill is expended for maintenance, it is clearly important for him to know something of the laws of maintenance—how its requirements vary as between different animals, how they are affected by the conditions under which animals are kept, how different feeding stuffs compare in value for maintenance, etc.—as well as to understand the principles governing the production of meat, milk, or work from the other half of his feed.

Farm animals must be supplied, therefore, with sufficient food to maintain their essential body functions before they can economically convert feeds into useful products or work. Inadequate nutrition leads to uneconomical production or faulty growth and development. A deficiency of essential nutrients in the ration, on the one hand, or overfeeding on the other will lead to nutritional diseases that may either impair the animal for further production or cause death. Adequate maintenance and the preservation of the health of farm animals enable them to use additional food for growth, development, and production.

MAINTENANCE NUTRITION SUSTAINS VITAL FUNCTIONS

Some of the essential body processes that are supported by the maintenance requirement are: (1) Heat production and the control of body temperature; (2) mastication, digestion, and assimilation of food and passage of material through the digestive tract; (3) glandular secretion; (4) circulation of the blood; (5) respiration; (6) normal muscular activity associated with a nonproductive life; (7) conduction of and response to nervous impulses; (8) excretion of waste products.

CONTROL OF BODY TEMPERATURE

Farm animals are warm-blooded and consequently must maintain their body temperature within rather narrow limits. The normal body temperature of all farm animals is usually above that of the surrounding air, so a continual supply of heat is required to keep the body warm. During the hottest days of summer the environmental temperature may at times approach or even surpass that of the body and at such times less heat is required to maintain body temperature. In winter, of course, more heat and consequently more food are required to keep the body temperature constant.

The principal means by which heat escapes from the body are radiation, conduction, convection, and the evaporation of water both from the surface of the skin, as sweat, and by respiration, in which heat is lost in vaporizing water in expired air. The control of these mechanisms is called physical regulation, and is accomplished mainly by increasing or decreasing the blood flow near the surface of the body to facilitate or retard heat loss and the evaporation of water. Within a certain range of air temperature physical regulation operates to maintain a practically constant body temperature without requiring a noticeable change in the rate of heat production.

If the environmental temperature continues to rise to a point where physical regulation of temperature is not sufficient to prevent the body heat from increasing above its normal level, there is an increase in body metabolism. This temperature is known as the point of hyperthermal rise. When the surrounding air temperature is decreased there is a minimum temperature at which the heat produced in the body is just sufficient to replace that lost without increasing metabolism. This point is known as the critical temperature. Below the critical temperature extra food must be oxidized in order to prevent the body from cooling off. This means of regulating body temperature is known as chemical regulation. The range of temperature between the point of hyperthermal rise and the critical temperature is known as the zone of thermal neutrality, and it represents the favorable air temperatures between which the metabolic rate, or heat production, is constant. Food is utilized most efficiently for maintenance or production when the air temperature is kept within the zone of thermal neutrality, and consequently a point within this favorable air-temperature range is established during experiments when the heat production during maintenance is being measured.

The approximate critical temperature for several species of farm animals has been determined. Preliminary work at the Agricultural Research Center, Beltsville, Md., indicates that the critical temperature of hens is about 28.3° C. (83° F.) and for chicks 1 to 4 days of age, 35.6° C. (96° F.). Other published values are: Pig, 21° C. (69.8° F.); steer with hair closely shaved, higher than 18.3° C. (64.9° F.); steer with full coat of hair, less than 15.6° C. (59.9° F.); dog, before clipping, 13.6° C. to 15.1° C. (56.5° F. to 59.2° F.); dog, after clipping, 23.8° C. to 26.5° C. (74.8° F. to 79.7° F.); and man with ordinary clothing, 15° C. (59° F.). These values are not constant and may become higher under such circumstances as exposure to cold winds and stormy weather, or when an animal's natural insulating coat of hair, wool, or feathers is sheared or clipped off. Fasting raises the critical temperature, while food consumption and good physical condition have the opposite effect. Diseases may also change the normal critical temperature of animals, depending on their effect on the complex heat-producing or heat-eliminating mechanism. This explains why well-fed, sheltered animals can stand cold weather much better than thin or underfed animals or animals that are exposed to wind and storm. Knowledge of the approximate critical temperature and heat production of animals and of the various factors which affect them is of use in estimating the amounts of heat and energy-producing foods which must be supplied for maintenance, and in providing for adequate ventilation, insulation, or heating in barns.

RELATIVE HEAT-PRODUCING VALUES OF FOOD CONSTITUENTS

Students of energy metabolism have known for many years that the three general classes of foods, carbohydrates (starches, sugars, cellulose, etc.), fats, and proteins, have different effects upon the heat production of fasting animals following ingestion. The consumption of protein causes the metabolic rate of heat production to increase much higher above a fasting level than an equal quantity of carbohydrate or fat. Rubner (1854–1932), a distinguished German scientist, called this effect of food in increasing the metabolic rate of animals "specific dynamic action," and this term has been widely used. In the United States the extensive early work of Graham Lusk (1866–1932) and associates on this subject is particularly noteworthy. Specific dynamic action as defined by Rubner can be illustrated by one of the last published statements of Lusk (*703*):

If what we now call the basal metabolism of a typical animal be 100 calories per day and if 100 calories be administered to the animal in each of the several foodstuffs on different days, then the heat production of the animal after receiving meat protein will rise to about 130 calories, after glucose to about 106 calories, and after fat to about 104 calories. These are typical average results.

A completely satisfactory explanation for this phenomenon has not yet been agreed upon. The heat produced in the body following consumption of food serves only to keep the body warm. Animals are never fed on single nutrients in practice, therefore heat-producing values of feeds or mixed rations and the factors influencing them are of most importance in estimating feed values. The heat production caused by the ingestion of a mixed ration is not a simple additive function of its component nutrients but a value which varies considerably with such factors as composition of the ration, plane of nutrition, kind and individuality of the animal, and conditions under which the measurements are made.

The Conference on Energy Metabolism previously mentioned (footnote 2, p. 431) outlined several terms with definitions for tentative adoption for use in energy metabolism studies. The term "heat increment" is suggested for the increase in heat production following and incident to the ingestion of any nutrient or ration. "Specific dynamic effect" is defined as the heat increment of a specific kind of nutrient and is therefore not logically applied to combinations of mixed nutrients as they occur naturally in feeding stuffs and in rations. The term "specific dynamic action" is reserved for the process, as distinct from the result, of specific dynamic effect. If these definitions are applied to the example from Lusk (*703*) quoted above, the specific dynamic effect of glucose under the conditions stated was equivalent to a heat increment of 6 calories per day (106 calories minus the basal level of 100 calories per day), and the process by which the food (in this case glucose) stimulates heat production above the basal level is the specific dynamic action.

Most of the digestible food in a balanced ration that is consumed for the purpose of maintenance or production consists of energy- and heat-producing nutrients. Other feed constituents, however, such as protein, minerals, vitamins, and water, which make up the remainder of the ration, are just as important as an adequate supply of energy or heat. Feeds such as grains and grain products which are high in total digestible nutrients are called concentrates. Feeds high in bulky, indigestible constituents, and consequently relatively low in digestible nutrients, are called roughages. The relative values of these feeds in meeting the requirements of animals depend upon the age of the animal and its digestive ability. Swine and poultry are unable to utilize large quantities of bulky foods to advantage and therefore are fed largely on concentrates, while ruminants (cattle, sheep, and goats) and horses have digestive systems capable of utilizing large proportions of roughages as well as concentrates.

Cellulose, a complex form of carbohydrate, is an important source of heat and to some extent of energy, especially for ruminants. Cereal straws, such as wheat and oat straw, and other bulky roughages high in fiber or cellulose are of considerable feeding value for maintenance heat production of adult cattle, sheep, and horses, especially during cold weather. These foods, however, are low in feeding value for growth, fattening, or other forms of production. This is because most of the food energy they contain is expended as heat incident to the greater work of mastication, digestion, and assimilation. This also explains some of the feeding value of browse, which though very bulky supplies the energy and heat requirement for maintenance for many thousands of cattle and sheep during the winter season, particularly in the Western States.

Proteins also may be used for heat and energy transformation in the body. They have approximately the same caloric value as the starches when utilized in this way, but it is usually uneconomical to depend upon foods rich in proteins as the major source of energy in maintenance or production rations, since only a portion of these compounds are available for this purpose and the remainder of the nitrogen-containing fraction is largely wasted. An equal weight of fat yields approximately two and a quarter times as much energy or heat as do the starches, sugars, or proteins. Even though the fats are the richest source of energy and heat for animals, it is necessary for starch or some other carbohydrate food that can be converted into sugar to be present in the body to aid in the last stages of fat oxidation. If there is a shortage of sugar in the body, resulting either from an inadequate supply of carbohydrates in the food or a derangement of carbohydrate metabolism in the body, certain harmful products of incomplete fat oxidation (acetoacetic acid, beta-hydroxybutyric acid, and acetone) will accumulate.

HEAT, ENERGY, AND PROTEIN REQUIREMENTS OF ANIMALS

Heat and energy transformation from absorbed food takes place in all the active, living tissues of the animal body. About 70 percent of the heat produced in the body comes from the skeletal muscles; most of the remainder originates from glandular activity (*285*). A constant source of energy is required to keep the skeletal or voluntary muscles in a state of tonus, or in a slightly contracted state, so that the animal can move about and have control over its posture, breathe, masticate food, etc. All of the muscles of the body are never completely relaxed during life. The involuntary muscles, which act independently of the will, also expend energy continually to maintain such important activities as blood circulation, passage of food and food residues through the digestive tract, and many others.

Activity increases the basal maintenance requirement for energy considerably, for example, a comparison of the metabolism of cattle during standing and lying indicates that the increase due to standing may be as much as 15 percent. Fat animals require more food per unit of body weight to maintain their live weight than thin animals. McCandlish and Gaessler (*711*) give some interesting data from limited observations on dairy cattle in high and low condition. They found that an average daily requirement of 0.62 pound of digestible crude protein and 6.67 pounds of digestible carbohydrate were needed per 1,000 pounds of live weight when the animals were in high condition, while 0.39 pound of digestible crude protein and 5.03 pounds of digestible carbohydrate per 1,000 pounds of live weight were adequate to maintain weight when the animals were thin.

Several methods have been used to measure the maintenance as well as the production requirement of animals. Direct measurements of heat production and respiratory gas exchange of animals has been the basis of many studies. Other methods involve the collection of urinary constituents and their correlation with the metabolism of specific nutrients and of the body as a whole. For example, Smuts (*1086*), working with Mitchell, recently measured the basal metabolism and total endogenous nitrogen excretion of several species and found that in mature animals 2 milligrams of nitrogen was lost from the body for every calorie of basal heat. Since 2 milligrams of nitrogen is approximately equivalent to 12.5 milligrams of protein (nitrogen × 6.25), it is possible to calculate from the basal heat the amount of protein catabolized by the body equivalent to the endogenous nitrogen losses.

Brody and associates (*157*), analyzed a large amount of basal metabolism data on animals varying in size from mice to elephants and found that the basal metabolism of the animals within this range tends to vary with the 0.734 power of body weight. The general equation showing the relation between basal metabolism in calories (Q) and body weight (M) was calculated to be $Q=70.5\ M^{0.734}$. In substituting the relation between endogenous nitrogen and basal metabolism in this equation, the amount of protein (P) required to replace the endogenous losses in maintenance of adult animals is $P=0.88\ M^{0.734}$. To convert P into food protein, Smuts recommends multiplying by 2 in order to provide a margin of safety. This assumes that the food protein is only 50-percent utilized. This method of calculation of the maintenance requirement of protein results in 0.35 pound of protein for a 1,000-pound animal and 0.465 pound in a 1,500-pound animal, which is considerably lower than amounts given in older standards determined largely by the feeding-trial method. This new method must be further tested with the larger domestic animals and under conditions found in practice before it can be applied to general use.

It has been recognized for a long time that some relation existed between body size and metabolism, and between body surface and metabolism. Since the smaller animals have a larger surface in proportion to their body weight, their metabolism must be greater per unit of body weight in order to replace the extra heat lost. Brody and associates and Kleiber (*633*), who have made significant recent contributions on this subject, are in approximate agreement on the relation between body weight and metabolism.

Similar studies on the relation of endogenous urinary nitrogen and neutral sulfur excretion in adult animals indicated that these substances tend to vary with the 0.72 and 0.74 powers of body weight, respectively. Since the difference in the numerical value of the exponent of body weight for each of the relationships studied is remarkably small, Brody and associates conclude that the ratio between body weight and basal metabolism and the relationship between endogenous nitrogen and neutral sulfur excretion tend to remain constant for mature warm-blooded animals. These workers have assembled extensive prediction tables on the basis of these findings, as well as a feeding standard for maintenance that includes total digestible nutrients, digestible crude protein, and calories for animals of widely different body weights.

These findings are interesting since they relate nutritive requirements for maintenance of many different kinds of animals to the single function of body weight. However, there is still some question whether economic maintenance can be accurately expressed as a function of body weight. The activity factor and other factors such as age, sex, breed, species, and environmental conditions, all of which affect economic maintenance, are no doubt variables that cannot be evaluated by the same power of body weight. Gaines (*405*), has come to the conclusion that his "working maintenance" of dairy cows varies most nearly with the first power, or is directly proportional to body weight. Morrison (*819*) has arbitrarily used the 0.87 power of body weight in the calculation of digestible protein and total digestible nutrients required for maintenance by dairy cows of various live weights.

The interesting relations revealed by these studies have contributed some substantial progress toward scientific evaluation of feeds and consequently of the economical feeding of animals. More work is needed, however, concerning the factors that affect the digestibility of feeds and rations by various species before individual feeds can be accurately evaluated in terms of feeding standards. Considerable additional work has to be done also in order to understand the needs of animals under the numerous conditions found in practice, and to discover more about the role of other specific food substances such as vitamins and minerals and the requirements of animals for these substances.

EFFECTS OF DIETARY DEFICIENCIES ON FEED UTILIZATION AND HEALTH OF FARM ANIMALS

QUANTITATIVE OR QUALITATIVE PROTEIN DEFICIENCY

The question of quantitative and qualitative protein deficiencies in the nutrition of farm animals is a matter of much concern to livestock men and a subject of considerable interest to research workers in nutrition. All animals require a source of protein in their diet to utilize for growth, for the replacement of body tissues and fluids, and for the production of such materials as milk and eggs.

Growing animals require a higher percentage of protein in their ration than do adult animals. Experiments with swine fed rations containing increasing amounts of protein on equal food intakes are reported by Mitchell and Hamilton (*800*). Their studies indicate that as the protein content of the diet is increased from a low level the rate of nitrogen retention, rate of growth, and utilization of energy increase with increasing protein to a level that is higher for the younger animal. Hammond, Hendricks, and Titus (*468*) report similar effects of protein on the growth and feed utilization of male chickens. The cockerels fed ad libitum during the first 14 weeks of life increased in efficiency on the basis of feed consumed up to a level of 21 percent of protein. After the birds were approximately half-grown there was only a slight difference in efficiency of food utilization down to as low as 15 percent of protein in the diet, and after maximum live weight had been attained 13 percent of protein in the diet was adequate for maintenance.

Proteins are very complex compounds made up of amino acids and other simpler compounds. The protein requirement of an animal is really a requirement for certain amino acids. At least 22 amino acids have been identified chemically, and 10 of these have been shown to be essential for the growth of animals. An essential amino acid is one that is needed by the body in some particular phase of metabolism but cannot be manufactured or synthesized by the organism. An amino acid is said to be nonessential if it can be synthesized or is not required by the organism. If a protein contains a large proportion and variety of essential amino acids it has a high biological value for animal feeding and is called a protein of good quality. A protein that is deficient in one or several essential amino acids is called a protein of poor quality, because its use by the body for structural purposes is limited. As a general rule, proteins of animal origin such as those found in milk or meat contain a higher percentage and greater variety of the amino acids necessary for growth than do the proteins of plant origin.

Most of the work with purified amino acids has been carried out with laboratory animals. The question of growth requirements has been investigated more thoroughly than that of other requirements. Little is known of the amino acid requirements for maintenance or for reproductive functions such as fertility, lactation, and egg production, although it is known that a supply of protein adequate from both the qualitative and the quantitative standpoints is essential if these processes are to be carried on to the physiological capacity of the animal. Physical work does not increase the protein requirement of an animal if it is receiving enough for adequate maintenance and growth and if the ration is adequate in energy-producing nutrients.

If the protein intake of an animal is inadequate either quantitatively or qualitatively the most obvious symptom is a slowing up or a complete cessation of growth together with very poor development of the skeletal muscles. An example of protein deficiency can be demonstrated by comparing the growth, fattening, and development of young swine on a ration of yellow corn alone with a suitable mineral mixture as compared to corn supplemented with milk or meat meal. Morrison (*819*) has summarized experiments of this kind and gives data to show that a ration of corn alone required nearly 700 pounds of grain to produce 100 pounds of live-weight gain, while a properly supplemented ration requires only slightly more than half as much grain. This demonstrates the usual results of uneconomical conversion of food into livestock gains when the protein content of the ration is inadequate qualitatively or quantitatively.

The nutrition of swine and poultry is improved if some source of animal protein such as milk, tankage, or fish meal is included in the ration in addition to plant proteins, while the Herbivora—cattle, sheep, and horses—can of course be adequately nourished after normal weaning by proteins from plant sources alone. Leguminous roughages such as alfalfa and clover are important sources of protein for herbivorous animals, but if the nonleguminous roughages such as timothy, grass hays, corn fodder, cereal straws, or browse are fed, it is usually advisable to add some protein concentrate to the ration. This is especially true for young growing or breeding animals and for heavy-producing animals such as dairy cows. Linseed, cottonseed, and soybean meals are typical plant protein concentrates used to supplement the rations of farm animals. A ration containing a mixture of proteins from several sources usually gives better results than one in which the protein is from a single source, since the amino acids of one protein will often supplement any amino acid deficiencies of the others. It is likely that some of the beneficial effects which feeds containing proteins of good quality have on the growth or production of animals may be due to other essential factors present in these feeds, such as riboflavin, nicotinic acid, etc.

In addition to poor growth and faulty muscular development a number of other abnormal conditions can result from rations low in protein. Pearson, Hart, and Bohstedt (*903*) have recently reported that a deficiency of amino acids interferes with the normal sexual rhythm of rats. However, no permanent sterility resulted from feeding diets qualitatively or quantitatively deficient in protein if adequate proteins were subsequently fed. Further studies, by Pearson, Elvehjem, and Hart (*902*), showed that regeneration of the hemoglobin level in nutritional anemia is affected by the level and quality of the dietary protein. These studies revealed that the proteins from liver or casein fed at a level of 4.8 percent permitted hemoglobin regeneration at approximately the same rate as the protein of corn or wheat gluten fed at about an 18-percent level.

A deficiency of protein or specific amino acids is one of the factors which can apparently lead to the development of certain intestinal lesions. Dogs develop peptic ulcers of the stomach and duodenum when maintained on a diet containing no animal protein and only a small quantity of vegetable proteins (*1197*). This same diet also results in a lowering of the blood proteins, or hypoproteinemia, and an accumulation of fluid in the tissues and the body cavities, known as nutritional edema. Weiss and Aron (*1200*) believe that certain peptic ulcers of dogs produced experimentally are a result of a specific amino acid (histidine) deficiency. Rats and mice also develop ulcerations of the stomach as a result of starvation or when fed diets deficient in quantity or quality of protein (*525*). Diets too low in protein or inadequate for growth because of qualitative deficiencies usually have an adverse effect on the appetite. This leads to lowered food consumption and a deficiency of other factors.

RELATION OF AN INADEQUATE INTAKE OF ENERGY-PRODUCING FOODS TO PROTEIN UTILIZATION

When an animal is receiving an optimum quantity of energy-producing nutrients in the form of carbohydrates and fats the amount of protein required for maintenance or production is reduced to a minimum. If the supply of energy becomes inadequate, some of the amino acids that should be used for protein nutrition are oxidized to furnish heat and energy. When amino acids are utilized in this way, the nitrogenous portion of the molecule is excreted as a metabolic waste in the urine because the body does not have the ability to convert this fraction into heat or energy. This causes an increase in food nitrogen lost from the body, and the efficiency of protein utilization is consequently lowered. To obtain maximum use of the protein in a ration it is, therefore, essential that the supply of nonprotein energy-producing foods be adequate.

If foods high in protein but relatively low in digestible carbohydrates and fats, such as alfalfa and clover, are fed without grain or other carbohydrate-containing supplements, as is commonly done in many sections of the country, considerable amounts of protein are used to furnish energy and heat, with a resulting wastage of nitrogen. Turk, Morrison, and Maynard (*1152*) supplemented alfalfa and clover hay rations for lambs with starch, sugar, corn oil, or corn grain to increase the energy content of the ration. They demonstrated that the biological value of the protein of these hays could thus be materially increased. The average of the biological values obtained was 81 for clover protein, 79 for alfalfa protein, 80 for the protein in the combination of clover and corn, and 77 for the protein in the combination of alfalfa and corn, while the unsupplemented alfalfa ration gave an average value of 50. These investigators proved conclusively that the low biological value obtained when alfalfa hay alone is fed is not due to an inferior quality of protein but to an insufficient supply of energy-producing food in the ration.

PHOSPHORUS DEFICIENCY AND FOOD UTILIZATION

Probably no dietary deficiency of livestock, particularly cattle, is so common the world over as a deficiency of phosphorus. A lack of this mineral in livestock rations is due primarily to a deficiency of phosphorus in the soils on which the plants used for feed are grown. The question of soil relationships to plant and animal nutrition received special attention in the 1938 Yearbook of Agriculture (*164, 737*). In the United States particular attention has been given to occurrence of phosphorus deficiency in Minnesota, Wisconsin, Michigan, Florida, Kansas, Montana, Utah, Texas, Pennsylvania, and California. The deficiency may be localized in certain areas within a State or may become evident only during seasons of drought.

Symptoms of phosphorus deficiency are similar in nearly all classes of livestock. Animals suffering from a lack of this mineral may soon be lacking in other factors as well, such as calcium, protein, vitamin A, etc., or they may develop toxic symptoms from consuming bones and putrid animal carcasses in an attempt to satisfy the deficiency. The symptom of depraved appetite is so common that this condition has been called the "bone-chewing" disease, though the animals may eat other things, including wood, hair, feathers, soil, and flesh, which are usually ignored under conditions of normal nutrition. As the deficiency progresses the animals develop low blood phosphorus and such symptoms as marked emaciation, stiffness of joints, loss of appetite, decreased milk flow, failure in reproduction, and a general unthrifty appearance.

The question of the effect of phosphorus deficiency on food utilization has been studied. Riddell and associates (*963*) at the Kansas Agricultural Experiment Station agree with the general conclusion of some previous workers that phosphorus deficiency is a limiting factor in the economical utilization of feed. They further conclude that this effect was not due to a lowered digestive ability of the animals but was a result of a higher energy metabolism as indicated by oxygen-consumption measurements. Kleiber, Goss, and Guilbert (*635*) also found no difference in the digestibility of the food, but there was slightly lower utilization of energy.

Forbes (*369*) has studied the question with laboratory animals and reports findings during a 10-week period of growth in young rats. In the first experiment the phosphorus-deficient rats had 15 percent less phosphorus in their bodies at the end of the experiment than the controls, but there was no difference in growth or utilization of energy and protein. In the second experiment a difference of 18 percent in body phosphorus was obtained by feeding a ration deficient in this mineral. In this case, a slight depression of the digestibility of food protein resulted without affecting protein and energy utilization or growth. Forbes states that there is a lack of clear-cut evidence that variations in the phosphorus content of the diet under conditions of practical nutrition affects the efficiency with which the food is utilized.

VITAMIN DEFICIENCIES AND FOOD UTILIZATION

The effect of vitamin D on the utilization of calcium and phosphorus in the diet is the most conclusive relation between food utilization and vitamins that has been demonstrated. In the absence of vitamin D large losses of calcium and phosphorus from the body occur in spite of a sufficient dietary supply of these elements, but when vitamin D is given losses decrease and unusual quantities of calcium and phosphorus are stored in the body until the normal balance is resumed. This is generally true for farm animals. Wallis (*1179*) has recently demonstrated it for mature lactating dairy cattle by feeding them rations deficient in vitamin D and keeping them away from direct sunlight.

On a vitamin-deficient diet the appetite usually decreases, less food is eaten, and the animal begins to lose body weight. The food that is eaten is used principally for maintenance. Production decreases because of lowered food intake, and consequently economical conversion of food into useful products is seriously interfered with. Braman and coworkers (*147*) have conducted a series of experiments with rats on the effects of diets deficient in vitamins A, D, and G during limited periods on the utilization of energy-producing nutrients and protein. They found that in rats with moderate vitamin A deficiency the most prominent effect was to depress the appetite, while the complete diet resulted in slightly larger weight gains and nitrogen storage. The experiment was terminated soon after the symptoms of vitamin A deficiency became acute. When the effects of a normal ration were compared with those of a ration containing an equal number of calories but deficient in vitamin D, the rats on the deficient ration excelled those on the normal ration in utilization of food nitrogen, in body protein gained, and in heat lost. The animals on the complete ration showed better appetite, gained in body fat, utilized more energy, and eliminated more carbon in the urine. Vitamin G deficiency also depressed the appetite of rats and they grew less and formed less body protein and fat. None of these vitamin deficiencies appreciably affected the digestibility of the protein or energy foods of the diets.

If a state of vitamin deficiency progresses to the point where violent digestive disturbances develop, such as the diarrhea produced by vitamin A deficiency or pellagra, absorption of food may become impaired. In such cases a deficiency of other factors may result in spite of an apparently adequate intake.

Effect of Dietary Constituents on Vitamin D Requirements

The amount of vitamin D in the diet necessary to meet the requirement of an animal can be modified by the presence or lack of other substances in the diet. Early studies indicated that an adequate supply of vitamin D was not the only factor necessary for normal calcium and phosphorus metabolism and bone formation. Vitamin D exerted its optimum effect only when there was an adequate supply of calcium and phosphorus in the diet and when these elements were present in certain proportions with respect to each other. When either calcium or phosphorus is deficient in the ration or there are abnormally large quantities of either, efficient assimilation of these minerals does not occur even in the presence of vitamin D. A normal calcium-phosphorus ratio usually falls within 2:1 or 1:2. There are species differences with respect to the effect of the calcium-phosphorus ratio on the assimilation of these substances. Huffman (*550*) reports that ratios as wide as 1:4 to 10:1 did not interfere with calcium and phosphorus utilization in dairy cattle.

An excess in the diet of salts of iron, magnesium, manganese, beryllium, strontium, thallium, and aluminum may interfere with phosphorus assimilation and favor the development of rickets even in the presence of adequate vitamin D, because these compounds tend to form insoluble compounds with phosphorus (*130*). Huffman (*551*) demonstrated that magnesium favored calcium and phosphorus metabolism and bone calcification in dairy calves. This action is described as a "vitamin D-sparing" effect; it is most evident on rations low in but not entirely devoid of vitamin D. There is little danger of these unusual relationships developing in practice unless excessive quantities of iron are given for treatment or for prevention of anemia or amounts of manganese are given far above the known required level.

Too large a proportion of phosphorus in proportion to calcium tends to favor the formation of the insoluble calcium phosphate, which is not so readily absorbed. Milk sugar, or lactose, favors calcium, phosphorus, and magnesium absorption from the intestinal tract. This action is similar to that of vitamin D, and accounts for some of the favorable effects of milk on the calcification of bone in young growing animals.

RESULTS OF OVERFEEDING

Overfeeding of farm animals can result in heavy financial losses by causing temporary or permanent disability and even death of animals. Money and labor are also wasted by supplying more feed than the animals can utilize. Livestock will frequently overeat if given an opportunity. The consequences may be only temporary digestive disturbances or they may be so serious as to cause death. The productive capacity of farm animals has in many cases been increased beyond the point where they are physiologically able to assimilate enough food to maintain the desired level of high production. In the attempt to maintain a record performance, owners may induce animals to eat more than they can continue to utilize, and unfortunate results usually follow. The animal is said to go "off feed," usually the result of a digestive upset. Such symptoms as diarrhea, constipation, bloat, colic, and failure to eat the usual quantities of food are danger signals, which if observed in time may be corrected. Digestive troubles from overeating may occur very suddenly, and even if the services of a veterinarian are immediately available a fatal outcome may not be prevented. Animals may be found dead in the morning without having shown any noticeable symptoms the evening before. Losses occasionally occur through accidental overfeeding, as when animals escape to the grain bin or into fields of abundant crops. Diseases due to overeating are best controlled by preventive measures, although some cases may be successfully treated by prompt medical and dietary attention.

Diseases from overeating of either balanced or unbalanced rations are an important cause of death among animals on a fattening ration. Newsom and Thorp (*853*) state that "overeating" may seem a peculiar designation for a disease, yet it probably causes more loss in the feed lots of Colorado than all other troubles combined. The "disease" as found in lambs has been called a variety of names descriptive of certain phases, such as apoplexy, indigestion, gastroenteritis, food intoxication, and diabetes. Animals may develop nervous symptoms such as head retractions, staggering gait, walking in circles, and rapidly progressing weakness, followed by prostration, coma, convulsions, and death. They may suffer for several days and then die or recover. Diarrhea is usually present when the animal lives more than a few hours. Acute cases usually have a marked glycosuria, or sugar in the urine, which suggests diabetes, but which has not been proved to be a true diabetic condition. Frequently the heartiest eaters and fattest lambs are the ones that die from this disease. Many feeders start culling out the fat lambs and selling them before the rest are ready in order to reduce the possibility of losses from this condition. Some lamb feeders become alarmed as the death toll rises and sell all their lambs before they have reached a desirable market finish, being forced to take a lower price for them and in many cases incurring a serious financial loss.

The exact cause of this disease and effective treatment of animals suffering from it still remain unsolved problems. Newsom and Thorp, in the reference previously cited, report work at the Colorado Agricultural Experiment Station in which the filtered (bacteria-free) intestinal contents from lambs dead of overeating were frequently found to be toxic to laboratory animals and sheep when injected but nontoxic when fed by mouth. The toxin in the filtrates was destroyed by heating to 60° C. (140° F.) or could be neutralized by antitoxins produced by bacteria of types B and D *Clostridium welchii*. Since bacteria of the *Clostridium welchii* group are normally found in the intestinal contents of sheep and other farm animals it seems probable that the character of the feed and overeating or conditions associated with a digestive disturbance may favor growth of the bacteria or excessive toxin production in the intestine, the absorption of which produces the disease. More work should be done on this important relation between dietary factors and the growth and toxin production of bacteria in the digestive tracts of animals.

Some preventive measures have been worked out that have helped considerably in holding large losses in check. Losses are often associated with heavy grain feeding and lack of exercise. If the grain allowance is reduced when deaths begin, losses usually cease; but a given level of grain feeding does not cause unfavorable results under all conditions. Among the puzzling features of this disease are its sporadic occurrence and the frequent failures encountered in attempts to produce it experimentally. Losses can usually be reduced to a minimum by starting lambs on feed slowly and gradually increasing the concentrate allowance, carefully watching the appetites of the animals and gaging the increase accordingly. Considerable success has been attained through self-feeding of lambs by grinding grains and roughage and mixing them in the desired proportions. The proportion of grain is increased as the feeding period progresses until a satisfactory fattening ration is established.

Cattle also are adversely affected by overfeeding. Frequent causes of heavy losses are bloat, indigestion, and acute distention or impaction of the stomach. "The eye of the master fattens his cattle" is a saying containing a wealth of advice. Satisfying the appetites of animals without feeding them beyond their ability to assimilate is the real problem.

Lactating animals, particularly dairy cows, also may be overfed, especially when record-breaking production is desired. Symptoms appear suddenly, the milk yield drops, and the animal begins to scour and refuses feed. Production which has fallen because of digestive disturbances is difficult to restore. Cows that develop milk fever incident to calving are usually high producers in extra-good condition because of abundant feeding. Sjollema (*1062*) recalls that both milk fever and acetonemia, or ketosis, were less frequent toward the end of the World War and just after it, a period when food was scarce. Metzger and Morrison (*786*) in studying the records of the Kentucky Agricultural Experiment Station herd found that a larger percentage of milk-fever cases occurred during the winter months and suggested a possible relation of the increased incidence at that time of year to factors affecting the calcium metabolism of the cattle, such as the quality of the roughage or the lack of ultraviolet radiation from sunlight or both.

The causes of milk fever and acetonemia are still not understood, but there is abundant evidence that they may be affected by nutrition, and this method of approach is being actively studied. Ketosis may occur in heavily fed, high-producing animals or in animals on a very poor ration. Chemical studies on the blood, milk, and urine of these animals show that they are unable to complete the oxidation of fats in the body and that the incomplete oxidation products, or ketone bodies (acetoacetic acid, acetone, and beta-hydroxybutyric acid), which are harmful to the body, accumulate in the blood and tissues and are excreted in the urine and milk. Moderate supplementary carbohydrate feeding, as of beet molasses, grain mixtures, etc., or good pasture tends to correct the condition if it has not progressed too far.

Calves overfed with milk frequently develop digestive disorders that may be followed by scours and pneumonia. Diarrnea caused by nutritional means must not be confused with that due to specific infections, although the control methods for either condition must be carried out simultaneously with rational feeding and good management.

Horses are very susceptible to overfeeding, especially during seasons when heavy work and consequent heavy feeding are followed by days of idleness. The grain ration should be reduced as much as 50 percent and the animals should be given an opportunity to get sufficient exercise when not working. Various digestive disturbances known collectively among livestock men as colic may be caused by errors in quantity as well as in quality of food. This is also true of heaves (broken wind) and founder. Azoturia, a disease known to some as "Monday morning sickness," is frequently fatal to horses; its development usually follows a period of insufficient exercise and heavy concentrate feeding.

When breeding animals are too fat as a result of overfeeding they frequently fail to breed normally. Asdell (*37*) points out that an overfat condition affects the male as well as the female, and that because show-ring fashion tends toward very fat animals, some of the best stock is impaired, leaving the more mediocre animals to perpetuate the race.

EFFECTS OF UNDERNUTRITION

Undernutrition is the result of either quantitative or qualitative deficiencies in the ration or both, or of a failure of the ingested food to become available to the body. The effect of dietary deficiencies on an animal depends on a number of factors, chief among which are the nature of the deficiency; age and kind of animal, and whether it is producing or nonproductive; duration of the deficiency; and whether or not the animal has stored the missing essential nutrients from previous adequate nutrition. A long-continued deficiency of vitamins and minerals usually leads to the development of the so-called nutritional diseases. A deficiency of other factors, such as a moderate energy or protein deficiency, tends to retard growth but is not particularly harmful if not continued too long, especially if the animal is neither pregnant nor expected to produce efficiently. The body has considerable ability to repair itself and resume growth if normal nutrition is established after a period of deficiency, but a shortage of certain nutrients can cause irreparable damage and must be avoided. When an animal is growing more slowly or not producing at an optimum rate because of an insufficient supply of food or of specific nutrients, .the major portion of the feed consumed is utilized for maintenance, and little or none is left for conversion into useful products or body increase.

Underfeeding of breeding animals, both male and female, greatly decreases their normal reproductive activity. The undernourished female may not come in heat regularly, and if she does become pregnant the young may not be carried to term, or if born, will probably be weak and unthrifty.

Pregnancy disease of ewes (*315*), or toxemia of pregnancy, is often associated with undernutrition of the pregnant animal. It is closely associated with a derangement of the carbohydrate and fat metabolism, and usually occurs during the last few weeks of pregnancy, particularly when the ewe is carrying more than one lamb. Ewes fed forage of poor quality with little or no grain, and lambing before the pasture season begins are usually in poor condition and most susceptible to the disease. Typical symptoms of this condition are the development of a staggering gait, weakness, evidence of impaired vision, grinding of the teeth, and failing appetite. Breathing is usually labored and rapid, and the animal becomes progressively worse, finally going down and being unable to rise. The animals often lie with the head turned to one side of the body and may remain in this position for several days until death. A very yellow or clay-colored liver is usually found at autopsy. This disease may occur in fat ewes if they do not have an opportunity to get sufficient exercise. Animals subjected to periods of feed shortage due to stormy weather or while in transit, may also develop the disease. Curative treatment is not usually successful and the mortality is high. Preventive measures through adequate nutrition and exercise have given best results.

McCay and coworkers (*716*) have published some interesting data on the effect of a calorie or energy deficiency in an otherwise apparently adequate diet on the length of life and development of the albino rat. These investigators retarded the growth of rats by limiting their intake of energy, while the control animals that consumed all they wanted of the same diet grew to maturity and developed much faster. Individuals in the retarded groups, however, lived much longer than the control animals. These studies suggest the possibility of modifying the growth of young animals and thereby extending their productive life. Maynard (*769*) discusses this question further and points out that the present standards for optimum nutrition, based largely on rapid growth and development, may not be an index of the life performance of the animal. This subject should be investigated further from the standpoint of farm-animal and human nutrition.

Sherman and Campbell (*1051*) have reported a series of experiments in which they have shown that a diet of natural foods apparently adequate for rats results in further nutritional improvement when enriched by the addition of powdered milk. They have studied particularly the effect of increasing the allowances of calcium, vitamin A, and riboflavin, all of which have contributed to improvement in nutritional well-being, health, and length of life. Increasing the calcium content of the diet resulted in both more rapid growth and longer life. This work further emphasizes the fact that the minimum quantity of a nutrient necessary for normal nutrition may be less than the amount required for optimum performance when measured by the effects on life span and when observations are continued into successive generations. These results should not be interpreted as conflicting with those of McCay and coworkers, previously cited. By using vastly different diets and experimental procedures these investigators have demonstrated other means by which the life span can be significantly increased above the present recognized normal standards. These observations should be regarded as introductions to additional fields of study, demonstrating that investigators in the field of nutrition should go beyond studies on specific short periods of growth, development, and maintenance, to include observations on length of life and lifetime production and the effects on successive generations, whenever possible or practical.

MEASURING THE ECONOMIC, OR PRACTICAL, MAINTENANCE REQUIREMENTS OF ANIMALS[4]

In accordance with the recommendation of the Conference on Energy Metabolism, referred to on page 431, the term "economic maintenance requirement" as used in the following discussion refers to the total quantity of feed required for the maintenance of body weight without material change in the composition of the living animal and for the performance of all involuntary and voluntary muscular activity; it does not include any feed that is used specifically for the performance of work or for the production of meat, milk, or eggs.

In factoring the total feed cost of work, meat, milk, or eggs it is very desirable to be able to measure or estimate the economic maintenance requirement. Furthermore, there are times when it is desirable to feed merely for the maintenance of live weight. For these reasons practical methods of measuring or estimating the economic maintenance requirement are of value to the student of animal nutrition and to the animal husbandman.

The simplest method of determining the economic maintenance requirement of an animal is to ascertain by trial and error just how much feed it must consume each day to keep from losing weight. This method is applicable to adult animals but not to growing animals, because normal growth and maintenance of live weight do not occur simultaneously in the same animal. Moreover, this method is not very precise because an adult animal may consume appreciably more feed for several days than it needs for maintenance and still not show a gain in live weight.

As yet no simple and dependable method has been devised for determining the economic maintenance requirement of the growing animal. The method tentatively suggested by Hendricks, Jull, and Titus (*504*) gives results that are definitely too low for all but the final stages of growth. However, it is possible to estimate the economic maintenance requirement of a growing animal by assuming that it is proportional to the 0.85 power of the live weight. It has not been demonstrated that this assumption is valid, but its use will give an estimate that probably does not differ from the true value by more than 15 percent.

If the average economic maintenance requirement of a group of adult animals of approximately the same live weight is desired, the following procedure may be followed: Carefully select at least eight animals of very nearly the same live weight and condition; roughly estimate the quantity of feed required daily for maintenance; feed to one of the animals slightly more than this quantity of feed each day, and to the other seven animals eleven-twelfths, ten-twelfths, nine-twelfths, eight-twelfths, seven-twelfths, six-twelfths, and five-twelfths, respectively, of the quantity of feed fed to the first animal; continue feeding the eight animals at these levels of feed intake until the animal receiving the least feed has lost about 15 percent of its initial live weight. If more than eight animals are available, or if greater accuracy in making the estimate is desired, more than one animal may be used at each of one or more of the higher and lower levels of feed intake.

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[4] This section was prepared by Harry W. Titus, Senior Biological Chemist, Bureau of Animal Industry

Plot the change in live weight of each animal against the quantity of feed it consumed daily as in figure 1. Draw a straight line through the plotted points, and the daily economic maintenance requirement will be the daily feed consumption at the point where the straight line crosses the horizontal axis. If an estimate of the standard error of this value is desired, the straight line, $d = sr + i$, may be fitted to the plotted points by the method of least squares and the standard error of i/s estimated in the usual way. In this equation,

d is the change in live weight;
s is the slope of the straight line;
r is the daily feed allowance;
i is the point at which the straight line intercepts the d axis; and
i/s is the point on the r axis at which it is intercepted by the straight line and, hence, is numerically equal to the daily economic maintenance requirement.

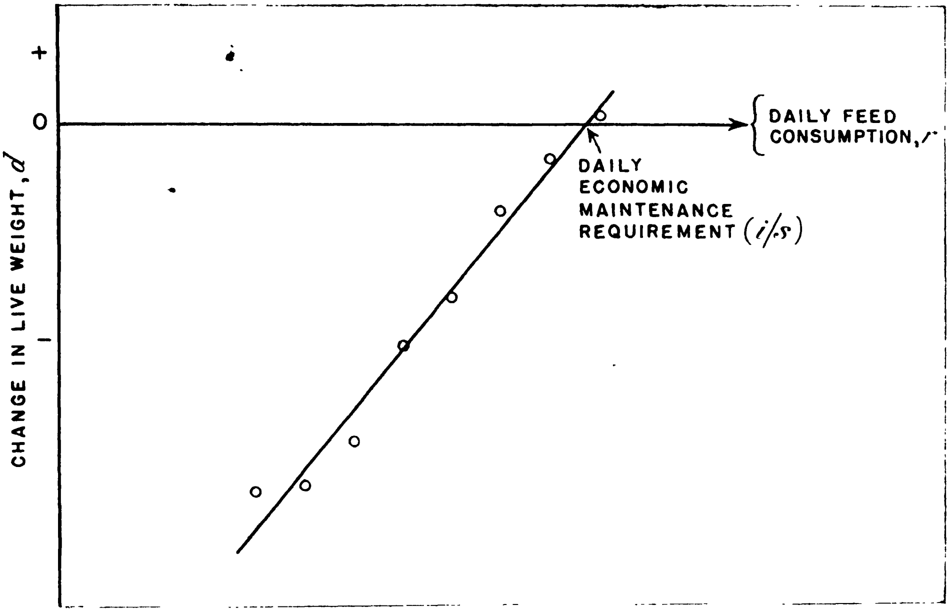

Figure 1.—Determining the economic maintenance requirement by feeding at approximately the maintenance level and at a series of submaintenance levels.

If the average economic maintenance requirement of a group of animals producing milk or eggs is desired, the general method of Wood and Capstick (*1252*), or the modifications of Titus (*1139*) and of Brody (*155*),[5] may be used. However, as was shown by Hendricks and Titus (*505*), the original method of Wood and Capstick may yield questionable results and hence should be used with caution. Nevertheless, this general method of attacking the problem of estimating the quantity of feed required for economic maintenance and for production holds much promise and deserves further study and application.

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[5] See also pages 12 to 23 of the reference given in footnote 2.

GROWTH, FATTENING, AND MEAT PRODUCTION

by O. G. Hankins and Harry W. Titus [1]

HERE is a discussion of some of the changes that occur in animals during growth and fattening—changes that affect the proportion of dressed carcass to total body weight, the proportion of edible meat, and the fat content of lean tissues. The article includes an account of the mathematical formulas proposed for comparing the efficiency with which different animals utilize feed for growth—a problem of great importance in both feeding and breeding.

FROM the standpoint of animal nutrition, growth is essentially a storage of protein. It is true that other substances are stored simultaneously, and that water is stored in even greater quantity than is protein; nevertheless, the growth of an animal is peculiarly characterized by the increase in the protein content of its body. Since protein is the most valuable constituent of meat, it can readily be seen that the growth of animals—especially of cattle, swine, sheep, and poultry—is the basis of meat production.

Aside from its importance in the production of food for man, growth plays an important part in man's efforts to learn more about animal nutrition. For example, growth, or gain in live weight, is often used (1) to detect nutritive deficiencies, (2) as the chief criterion in comparisons of two or more diets or feeding systems, (3) for the evaluation of the quality of proteins, and (4) in measuring the quantity of certain vitamins in feeding stuffs.

The growth of an animal is most commonly measured by the increase in its live weight, although at times increase in height, length, or girth, or some other characteristic may be used. If the live weights of an animal at different ages are plotted against the corresponding ages, a growth curve similar to that in figure 1 is obtained; but if the same live weights are plotted against the quantities of feed required to attain them, the resulting curve is like that in figure 2.

If, in a similar manner, the efficiency of feed utilization—the ratio of the gain in live weight to the weight of feed required to produce the gain [2]—is plotted against age and against live weight, respectively, curves similar to those in figures 3 and 4 are obtained. Efficiency of feed utilization is a straight-line function of live weight—that is, it decreases in direct proportion to the increase in live weight—and this simple relationship makes comparisons relatively easy. A method of measuring and comparing the efficiencies of individual

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[1] O. G. Hankins is Senior Animal Husbandman and Harry W. Titus is Senior Biological Chemist, Bureau of Animal Industry.

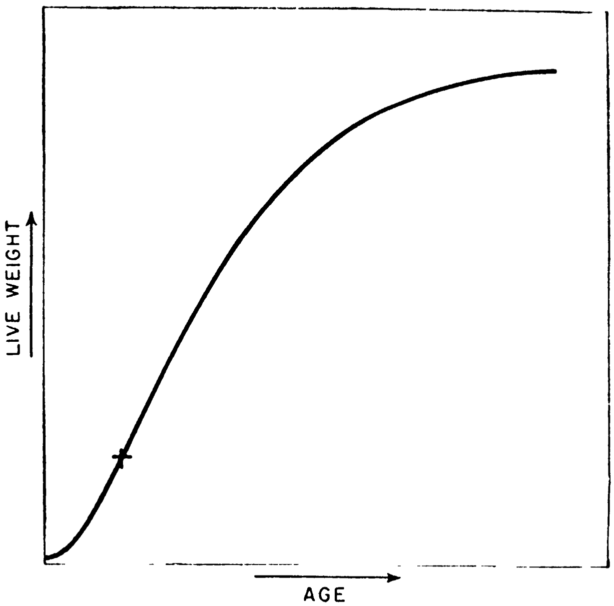

Figure 1.—The relation between live weight and age; the cross marks the point of inflection, at which growth reaches its maximum rate.

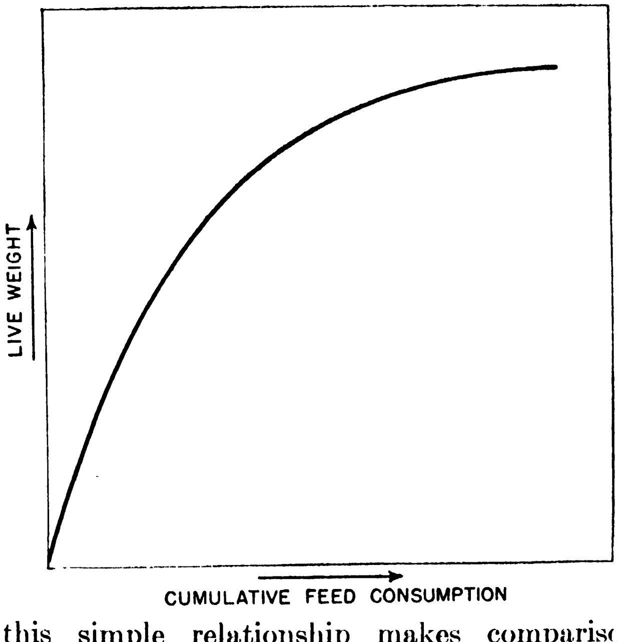

Figure 2.—The relation between live weight and cumulative feed consumption.

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[2] For example, if it takes 3 pounds of feed to make 1 pound of gain in live weight, the efficiency of feed utilization is one-third, or a little more than 0.33. The efficiency of feed utilization is always a fraction—that is, less than 1.

animals, or of groups of animals, in utilizing feed is presented in some detail, for readers with a technical background, at the end of this article.

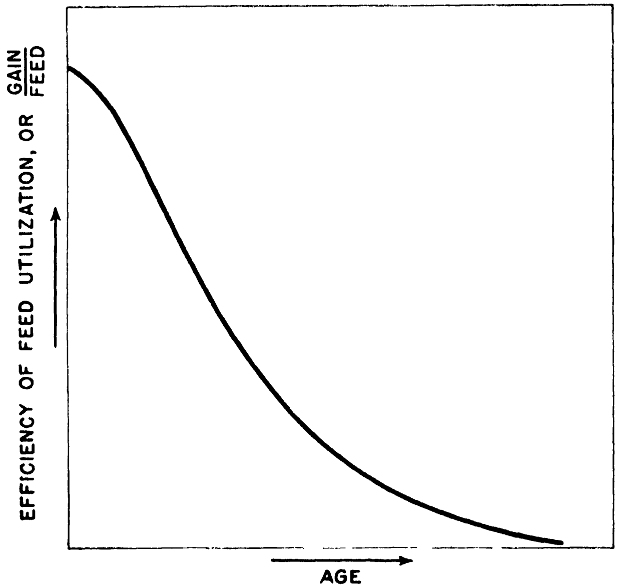

Figure 3.—How the efficiency of feed utilization decreases as the age of the animal increases.

In general, the growth curves of most animals, with the exception of man, are very similar. In man the growth curve indicates that there are at least two major growth cycles,[3] whereas in most other animals there is a single major growth cycle. This single cycle is

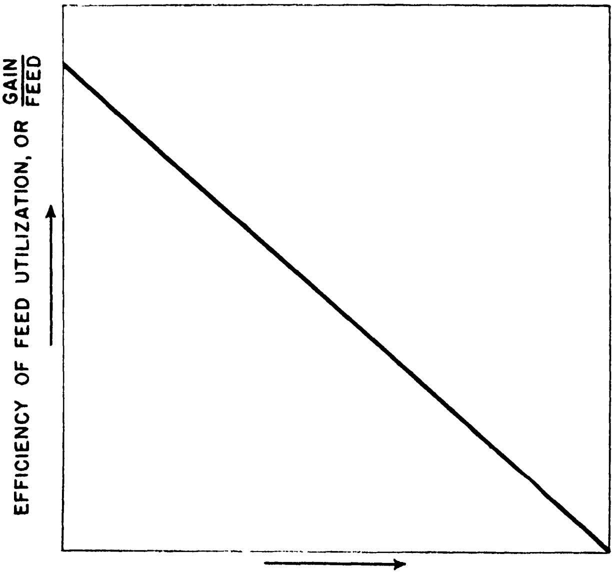

Figure 4.—How the efficiency of feed utilization decreases as the live weight of the animal increases.

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[3] In man the first cycle ends and the second cycle begins at the age of about 3½ years. The second cycle continues until growth is complete.

illustrated in figure 1, which shows that growth proceeds at an increasingly rapid rate until a certain point is reached, after which it proceeds at a decreasingly rapid rate until it is completed. The point at which the rate of growth reaches its maximum, indicated by + in figure 1, is called the point of inflection. In some species of animals the first part of the cycle up to the point of inflection is relatively short, but in others the two parts of the cycle are of nearly equal length.

Various factors, such as inheritance, relative completeness of the diet, and rate of feed consumption, affect the shape of the growth curve (fig. 1). Growth may readily be limited by limiting the feed consumption of an animal, but it is difficult, if not impossible, to stimulate growth by nutritional means beyond the animal's inherited growth capacity.

Whereas the gains of the young growing animal usually are composed largely of protein and water, those of the mature or nearly mature animal consist mostly of fat. It usually is not possible, however, to fix any definite point as the one at which growth ceases and fattening begins. This is because the character of the gain varies during both the early and the late stages of growth, and, normally, the change between the period when the gain is mostly protein and the period when it is mostly fat is not abrupt but gradual.

The changes in the character of the gain as the animal grows and fattens are reflected strikingly by changes in the ratio of carcass weight to the weight of the entire body and in the various characteristics of the carcass and its components. These latter changes are of particular interest and importance as they occur in meat animals. It is the purpose of this article to set forth the principles involved in the more important phases of the subject and, so far as space will permit, to present examples of their application to different species of meat animals.

EFFECTS OF GROWTH AND FATTENING OF MEAT ANIMALS

PROPORTION OF DRESSED CARCASS TO TOTAL BODY WEIGHT

One of the most obvious and best known of the changes that accompany growth and fattening is the increase in proportion of dressed carcass based on live weight of the animal, or the ratio of carcass weight to the weight of the entire body. This point is well illustrated in figure 5, which presents results from more than 5,000 normally fed hogs that varied from approximately 60 to 380 pounds in final feed-lot weight. It is of marked interest and significance that with this increase in weight, when accompanied by normal change in the character of the gain, the proportion of carcass, or the dressing percentage, increased from about 67 to 80 percent. This means, for example, that whereas the average 100-pound pig may be expected to yield about 71 pounds of dressed carcass (which in the case of this species includes the head), the 200-pound hog may be expected to produce approximately 152 pounds of dressed carcass, or 10 pounds more than twice as much as the 100-pound pig. Likewise, the 300-pound hog would yield a dressed carcass weighing approximately

237 pounds, or about 24 pounds more than three times as much as that of the 100-pound pig. Such disproportionate increases in carcass weight mean much in the livestock and meat industry and to the consuming public, mainly because they represent similar increases in the proportion and energy value of the edible product and, generally speaking, in monetary value.

The dressing yields of cattle range from approximately 42 to 60 percent and those of unshorn lambs from approximately 33 to 53 percent. The dressed weight of chickens, after bleeding and picking, is about 80 to 93 percent of the live weight; and the full drawn weight—the weight after bleeding and picking, removal of the head, feet, and entrails, and replacement of the heart, liver, and empty gizzard—is approximately 60 to 87 percent of the live weight.

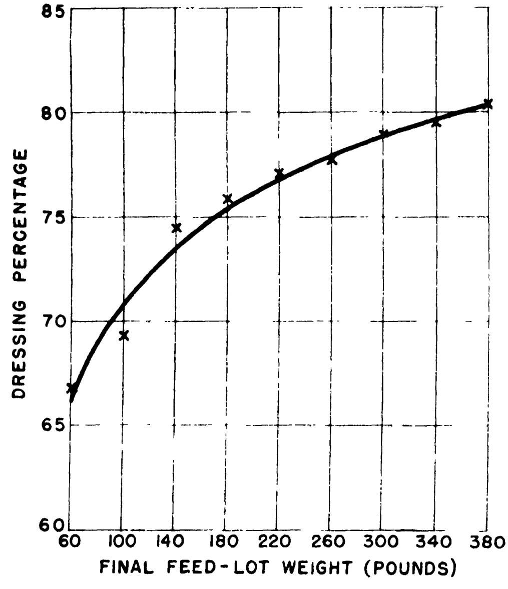

Figure 5.—Final feed-lot weight and dressing percentage of hogs increase together. Crosses represent averages of the several final feed-lot weight groups considered in the study.

PROPORTIONS OF PARTS OR CUTS

After considering the increase in proportion of dressed carcass as a result of growth and fattening, it is logical to give attention next to the changes that occur in the proportions of the different parts of the carcass. For the present purpose these parts probably are best represented by the common primary cuts, such as leg, loin, rib, shoulder, breast, and neck in the case of lamb. The public is accustomed to think of the carcass in terms of these cuts and is familiar with their respective advantages and disadvantages as well as the relative consumer demands for them. Any significant increase or decrease in proportion of a cut, especially if it is a major cut, is a matter of definite importance, mainly because of its effect on carcass value.

Tables 1, 2, 3, and 4 indicate some of the changes in proportions of cuts that occur with growth and fattening of hogs, cattle, lambs, and chickens, respectively. It will be noted (table 1) that as the hog grows and fattens the percentages of ham, loin, shoulder, and head cut from the dressed carcass decrease. Ham and loin are two of the pork cuts for which there is greatest demand and which are relatively high in price. Shoulder is intermediate in this respect, while the head represents relatively low-priced product and therefore a reduction in the percentage of that cut is an advantage rather than a disadvantage. On the other hand, the table shows increases in bacon and cutting fat, those in cutting fat being remarkably large. While increase in bacon is desirable and represents an improvement, more fat ordinarily is considered undesirable.

TABLE 1.—*Average percentages of certain parts of hog carcasses classified according to live weight of animal* [1]

Hogs, carcasses, and parts	Data for hogs weighing—				
	Less than 130 pounds	130 to 159 pounds	160 to 199 pounds	200 to 249 pounds	250 pounds or more
Hogs number	26	41	199	240	92
Average live weight at slaughter pounds	106	146	183	218	289
Average weight of chilled carcass do	78.0	116.0	146.0	177.5	238.5
Hams [2] percent	19.9	18.4	18.4	17.5	17.0
Loins do	13.2	12.2	12.1	11.6	11.0
Bacons do	9.4	10.1	10.8	11.4	11.9
Shoulders (3-rib, full cut) do	18.5	17.7	17.4	17.0	16.7
Head do	10.7	9.8	9.4	8.9	8.5
Cutting fat [3] do	10.9	15.0	16.8	19.5	21.5

[1] Data from Warner, Ellis, and Howe (*1182, p. 250*).[4]

[2] Percentages of parts based on weight of chilled carcass.

[3] Consisting of back fat, leaf fat, and fat trimmings.

The results of a cooperative study by the Michigan Agricultural Experiment Station and the Bureau of Animal Industry showed, in part, that the percentage of prime rib cut of Hereford steers, based on empty-body[5] weight, increased with increase in fatness of the animals (table 2, fig. 6). The percentages of plate, flank, and short loin also increased, while the percentages of round, loin end, and foreshank decreased. In chuck there was no definite trend, and in rump the percentage tended to increase although the change was small.

TABLE 2.—*Average percentages of certain parts of carcasses of full-fed Hereford steers classified according to fatness*[1] *and average weights of the animals and carcasses* [2]

Steers, carcasses, and parts	Data for carcasses containing indicated proportions of fat [3]					
	12 to 15.99 percent	16 to 19.99 percent	20 to 23.99 percent	24 to 27.99 percent	28 to 31.99 percent	32 to 35.99 percent
Steers number	4	8	5	11	6	2
Final feed-lot weight pounds	604	748	769	809	883	972
Live weight at slaughter do	593	723	740	789	850	944
Empty-body weight do	557	679	711	751	832	918
Chilled carcass weight do	342.0	425.5	433.8	477.1	533.1	603.0
Parts of carcass—percent of empty-body weight:						
Forequarters percent	31.06	31.54	31.19	32.14	32.58	33.22
Prime rib cuts do	5.15	5.36	5.36	5.75	5.91	6.29
Chucks do	16.66	16.73	16.18	16.29	16.73	16.39
Plates do	6.67	6.98	7.22	7.82	7.91	8.45
Foreshanks do	2.60	2.43	2.32	2.17	2.16	2.05
Hindquarters do	29.11	30.41	29.25	30.77	31.00	31.70
Rounds do	13.32	12.99	12.50	12.02	12.03	11.09
Rumps do	2.93	2.93	2.83	2.97	2.99	3.01
Flanks do	2.30	2.99	2.92	3.55	3.65	4.15
Loin ends do	5.84	5.74	5.23	5.50	5.39	5.32
Short loins do	5.06	5.78	5.57	6.46	6.73	8.13

[1] From unpublished data of the Michigan Agricultural Experiment Station and the U. S. Bureau of Animal Industry.

[2] The 36 steers ranged from approximately 11 to 17 months of age at slaughter.

[3] Based on ether-extract content of right side.

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[4] Italic numbers in parentheses refer to Literature Cited, p. 1075.

[5] The entire animal exclusive of the contents of the stomachs, intestines, and bladder is known as the "empty body."

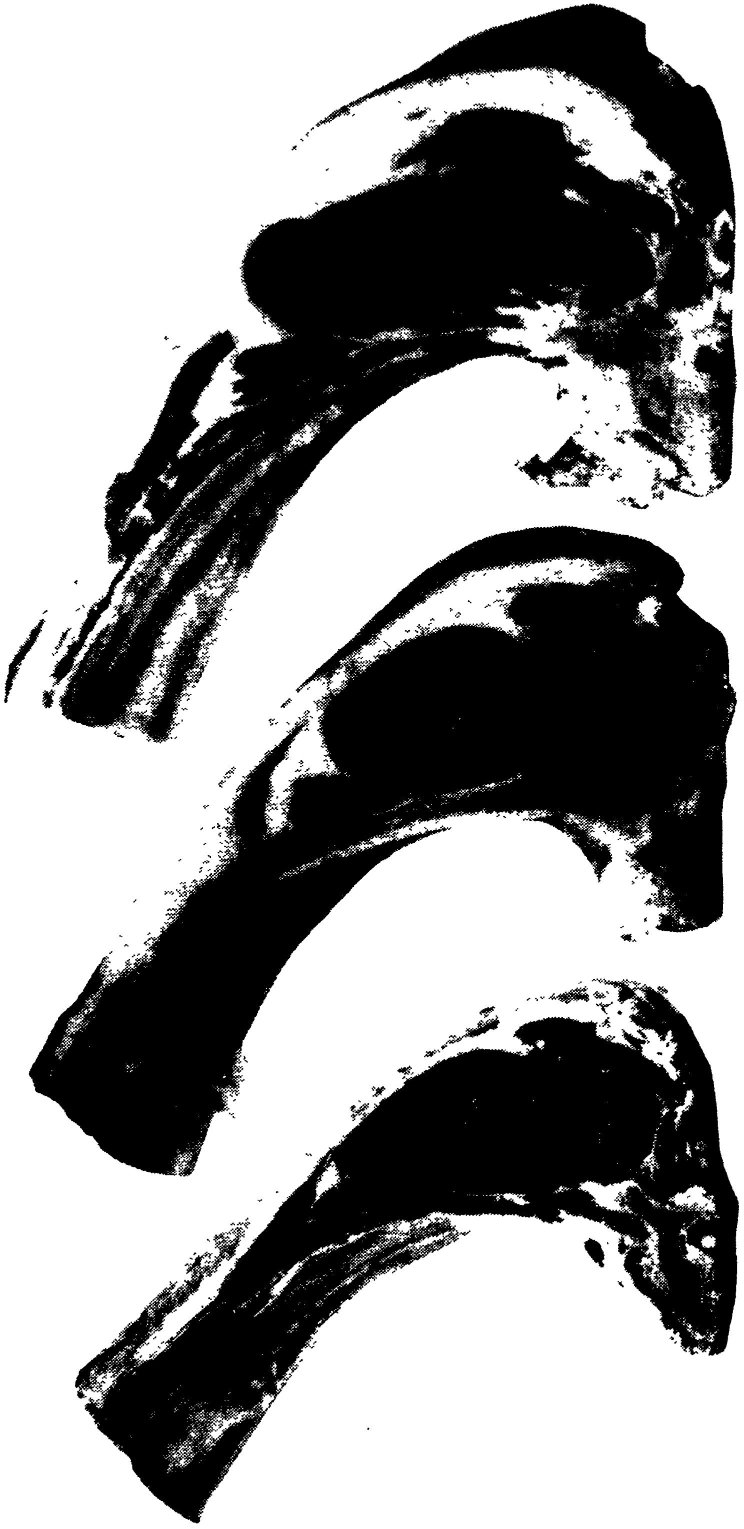

Figure 6.—Rib cuts illustrating growth and fattening of cattle associated with increase in live weight from approximately 600 to 900 pounds. This increase in size also represents an increase in the proportion of this important cut in the carcass.

Table 3 shows that with an increase in the carcass weight of lambs from approximately 22 to 48 pounds, which was accompanied by a change from "thin" to "fat," there was a tendency for the percentages of leg, shoulder, neck, and probably breast to decrease. Only one of these four cuts—the leg—is included among the most preferred cuts from the lamb carcass. On the other hand, the rib and loin tended to increase, and both of these cuts are very popular and relatively high in price.

TABLE 3.—*Average percentages of certain parts of lamb carcasses classified according to fatness* [1]

Carcasses and parts	Data for carcasses containing indicated proportions of fat [2]			Carcasses and parts	Data for carcasses containing indicated proportions of fat [2]		
	Under 20 percent	20 to 34 percent	35 percent or more		Under 20 percent	20 to 34 percent	35 percent or more
Carcasses ..... number.	13	19	10	Shoulders (3-rib) percent	19.73	19.53	18.80
Average weight of chilled carcass ..... pounds.	21.9	34.4	47.5	Loins..........do..	7.64	9.08	9.78
Trimmed legs..percent..	30.17	25.60	26.14	Neck..............do	3.89	3.28	2.91
Rib cuts (9-rib) ..do..	15.31	16.83	17.92	Breast..........do....	15.32	15.36	14.83

[1] From unpublished data of U. S. Bureau of Animal Industry.

[2] Based on ether-extract content of edible portion.

Table 4 shows that as the live weight of White Plymouth Rock cockerels at the Illinois Agricultural Experiment Station (*797*) increased from 0.5 to 7 pounds, the weight of the legs above the hock and of the torso, when expressed as percentage of the empty-body weight, increased materially. The percentage of skin increased to some extent, while that of wings tended to decrease after the birds attained a live weight of 3 pounds. No distinct trend in percentage of neck was observed.

TABLE 4.—*Average percentages based on empty-body weight of parts of carcasses of 15 White Plymouth Rock and 70 White Leghorn cockerels at increasing weights and stages of growth and fattening*

Breed of chickens and parts of carcass	Data for birds of approximate slaughter weight of—								
	0.5 pound	1 pound	1.5 pounds	2 pounds	3 pounds	4 pounds	5 pounds	6 pounds	7 pounds
White Plymouth Rock:	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Skin....................	6.5	7.8	7.7	7.3	7.0	7.4	8.1	7.6	8.5
Neck....................	3.7	3.5	3.3	3.9	3.7	3.7	3.4	3.4	3.4
Legs above hock..........	16.2	18.0	19.0	20.2	21.5	22.1	22.1	22.2	24.9
Wings....................	6.5	6.4	6.3	6.4	6.7	6.6	5.9	5.9	5.7
Torso....................	21.3	22.5	22.4	22.0	23.4	24.6	25.0	26.4	26.9
White Leghorn:									
Skin....................	7.08	6.52	6.47	6.43	6.82	7.16	6.65	....	....
Neck....................	3.59	3.61	3.24	3.21	3.34	3.10	2.85	....	....
Legs above hock..........	15.60	17.30	18.80	19.70	21.20	20.90	21.60	....	....
Wings....................	6.65	6.93	6.98	7.03	7.29	6.74	6.41	....	....
Torso....................	20.50	23.30	24.00	25.10	25.40	26.60	26.70	....	....

With White Leghorn cockerels, likewise, at the Illinois Agricultural Experiment Station (*798*), marked increases were noted in the proportion of legs above the hock and of torso. No definite trend of the percentage of skin was found, but the percentage of wings increased up to a live weight of 3 pounds and then decreased. The proportion of neck decreased slightly.

CHEMICAL COMPOSITION OF MEAT ANIMALS

The chemical composition of the empty body of meat animals is generally regarded as the most significant measure of the stage of growth or fattening that has been attained by the individual animal. But probably the greatest significance of chemical composition and the changes in it associated with growth and fattening is as an index of the nutritive value of the edible product from meat animals for human consumption.

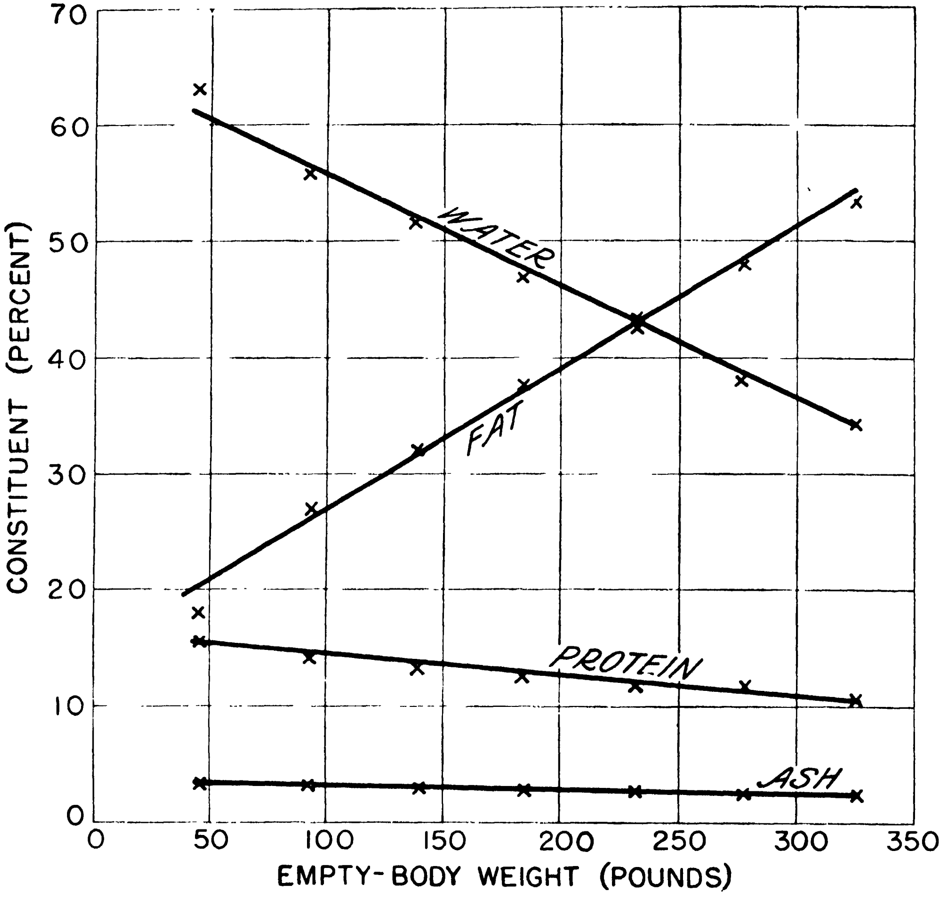

Figure 7.—The percentages of water, protein, and ash in the empty body of hogs decrease and the percentage of fat increases as the animals increase from approximately 50 to 325 pounds in empty-body weight. Crosses represent averages of the several weight groups considered.

Chemical composition is usually expressed in terms of the percentages of protein, water, fat, and ash or mineral matter. As previously indicated, the gains of the younger growing animal are usually composed in large part of protein and water, whereas those of the more mature or nearly mature animal consist mostly of fat. In consequence, as the live weight increases beyond a certain value it is generally true that the proportions of protein and water in the animal tend to decrease and the proportion of fat to increase. The proportion of mineral matter does not change greatly but under usual conditions decreases slightly.

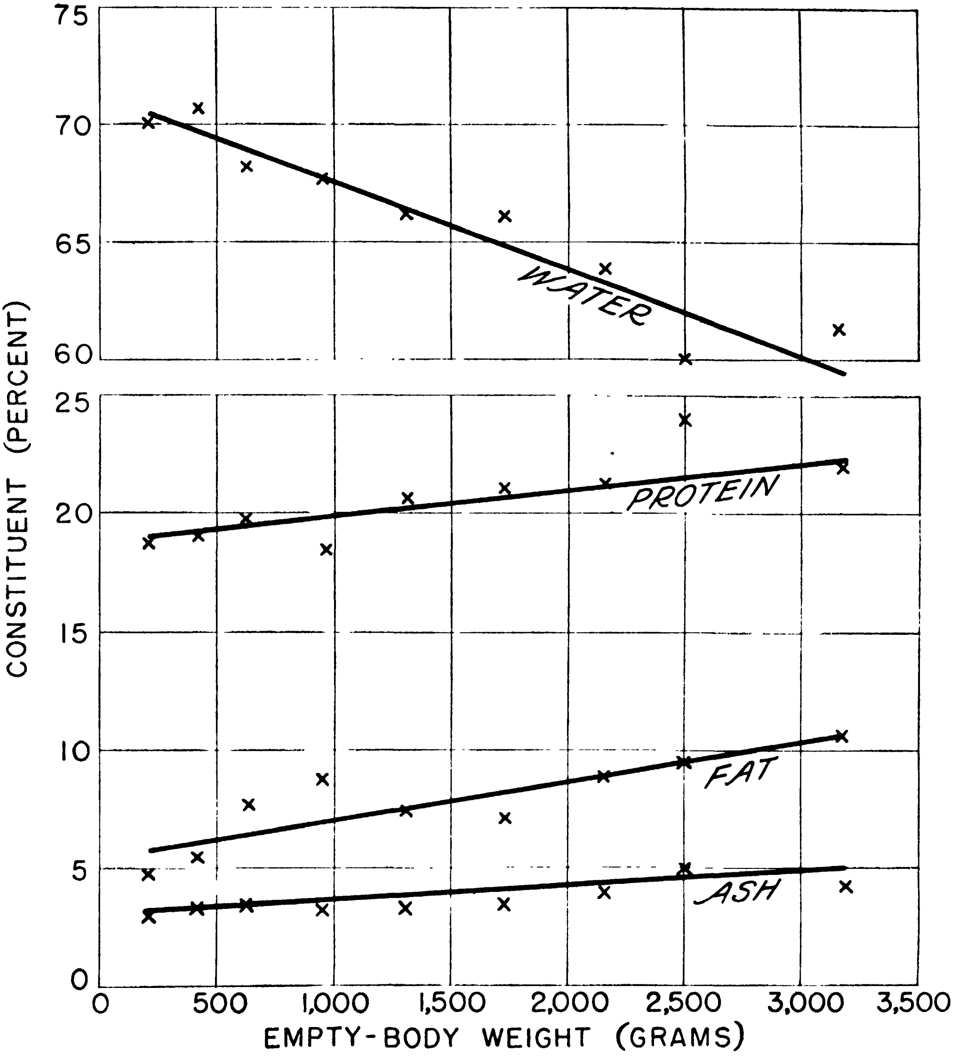

Figure 8.—The percentage of water in the empty body of White Plymouth Rock cockerels decreases and the percentages of protein, fat, and ash increase as the chickens increase from approximately 200 to 3,200 grams in empty-body weight, or 0.5 pound to 7 pounds in live weight. Crosses represent averages of the several weight groups considered. (Based on data from Illinois Agricultural Experiment Station Bulletin 278 (*797*).)

The changes in composition that generally occur are well illustrated in figure 7, which shows the change in the composition of hogs ranging from 50 to 325 pounds in empty-body weight. The changes in water and fat content are striking. The water content decreased from approximately 60 to 35 percent, while the fat (ether extract [6]) content increased from about 20 to 55 percent. At the empty-body weight of approximately 230 pounds the water and fat percentages were equal. Accompanying these changes in water and fat content, the protein decreased from about 16 to 10 percent and the mineral matter from about 3 to 2 percent.

Such information gives a quick, reasonably satisfactory, though somewhat rough, estimate of the relative nutritive values of the edible portion of the hog at different stages of growth and fattening. For example, based on values in figure 7, calculations show the caloric or heat value per pound of the 250-pound hog to be approximately 25 to 30 percent greater than that of the 150-pound hog. The difference is due mainly to the higher percentage of fat in the heavier hog. More accurate estimates, of course, can be made in cases where the composition of the edible portion itself is known.

Exceptions to the general rule relating to changes in chemical composition, indicated above, are known to exist. An example of such exceptions is found in data obtained at the Illinois station in work on chickens. As shown in figure 8, accompanying a decrease in water content from approximately 70 to 60 percent there was a tendency not only for fat but also for protein and ash to increase in percentage, associated with an increase in live weight of White Plymouth Rock cockerels from about 0.5 pound to 7 pounds. Thus it is shown that the decrease in water content, which appears normally to be a function of growth and fattening, is not always compensated for, in its entirety, by increase in fat content. Such variations are believed to be due to species differences.

DISTRIBUTION OF FAT

As is rather generally known, animals do not store fat evenly throughout their bodies. The fat is normally deposited at widely varying rates in different parts of the body, which results in marked variation in the proportions of fat found in different parts when the animal is slaughtered for meat. This fact is obviously not only of scientific interest, but also of definite practical significance through its effect on the food and energy values of the meat from various parts of the animal body.

Figure 9 shows the changes that occurred in the percentages of fat that could be separated from the rib, loin, breast, neck, shoulder, and leg cuts of lamb, while the separable-fat content of the dressed carcass increased from approximately 5 to 37 percent. At low levels of the latter there were only small differences between the several cuts. However, generally speaking, the fat content of the cuts soon began to diverge, with the rib, loin, and breast tending to group themselves at a higher level of fatness and the neck, shoulder, and leg cuts at a lower level. It is also noteworthy that when the separable-fat content of the carcass became about 22 percent, that of the leg began to fall below that of all other parts. After the separable-fat content of the carcass attained a value of approximately 28 percent the rib cut tended to be fatter than all other cuts. At the extreme of 37 percent in separable-fat content of carcass there was a difference of about 30 percent between rib, the fattest cut, and leg, the cut containing the least fat. The loin tended to be next to the rib in fat content, but at high levels of carcass fatness the gains in the former did not keep up with those of the latter. Breast, neck, and shoulder were intermediate at the high levels of carcass fatness and were not greatly different from each other.

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[6] "Ether extract" is often used interchangeably with "fat" because in the analysis of foodstuffs the total material extracted by ether is largely fat.

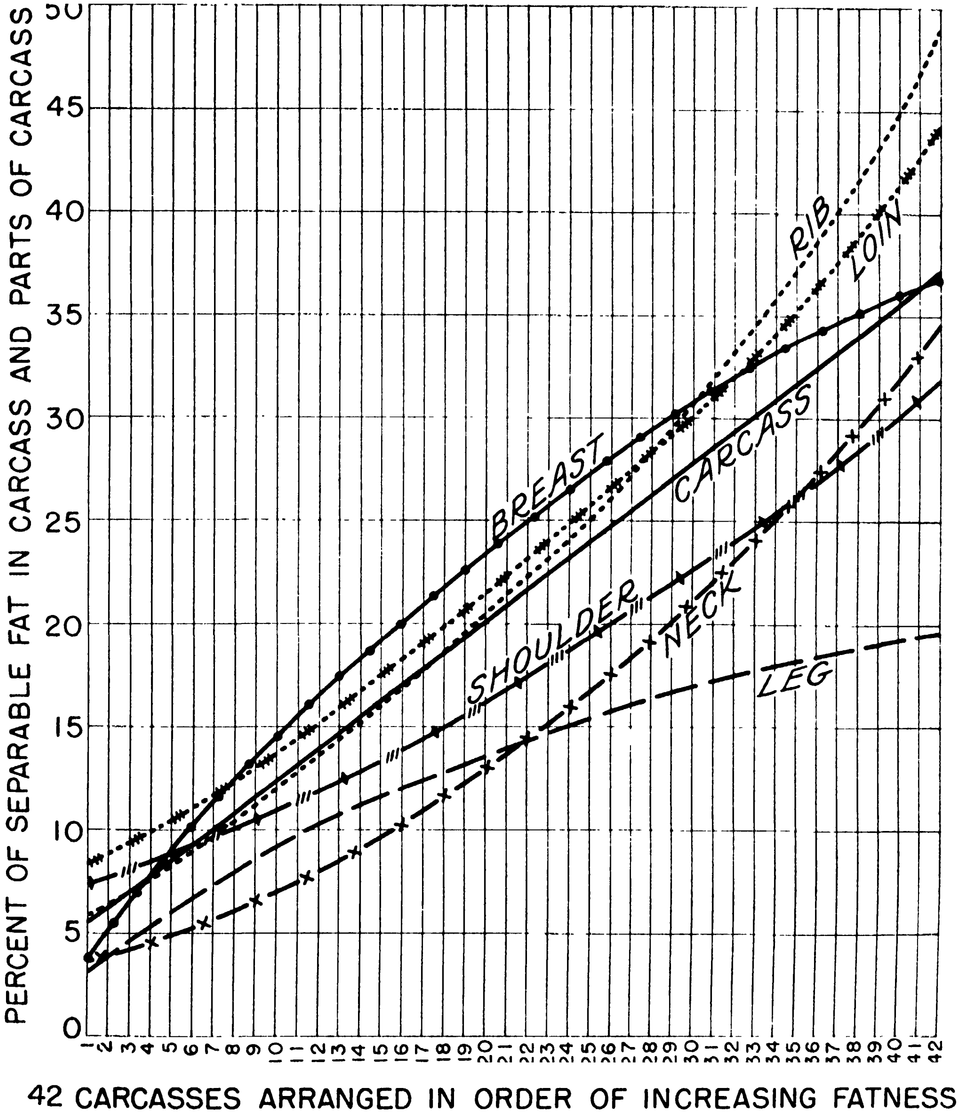


Figure 9.—Comparative increases in the separable-fat content of rib, loin, breast, neck, shoulder, and leg cuts of lamb as the separable-fat content of the dressed carcass increases from approximately 5 to 37 percent. (Based on unpublished data of the U. S. Bureau of Animal Industry.)

FAT CONTENT OF LEAN TISSUE

Although it is believed to vary greatly with species, the ability of animals to store fat within their muscle or lean tissues is of much interest and significance. Considering the heat or energy value of fat per unit of weight to be about 2.25 times that of other energy-producing nutrients, it is obvious that when fat occurs in muscle the energy value of the "lean meat" is materially increased. Moreover, intramuscular fat is regarded as having an influence on several other quality factors of meat, including color, firmness, and marbling of lean and behavior in cold storage, or the ability to withstand storage at a temperature slightly above the freezing point for a relatively long period without spoiling. It is even believed to have an effect on some of the palatability factors of cooked meat, such as the quality or richness of juice.

Graphic evidence of the occurrence of fat (ether extract) in muscle or lean tissue and of the changes in amount of this fat associated with increase in fatness of the dressed carcass is presented in figure 10. These results were obtained on high-grade yearling Hereford steers as a part of a cooperative study by the Michigan Agricultural Experiment Station and the Bureau of Animal Industry. It will be noted that the fat of the "eye" muscle, which is the large back muscle, ranged from about 1.8 to 6.5 percent while the fat of the entire dressed carcass ranged from about 12 to 34 percent. Of special interest is the fact that the relationship is much better represented by a curve than a straight line. The curve shows that the fat content of the muscle increased relatively much faster after the fat content of the dressed carcass had reached 24 percent than at lower stages of fatness.

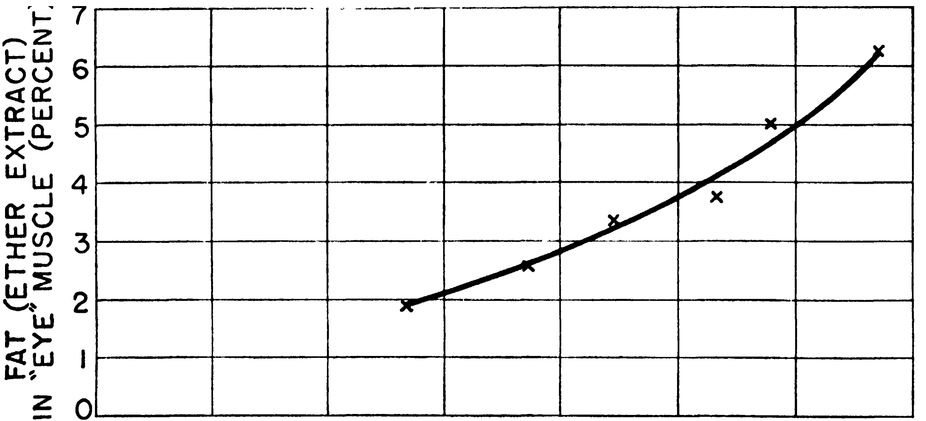
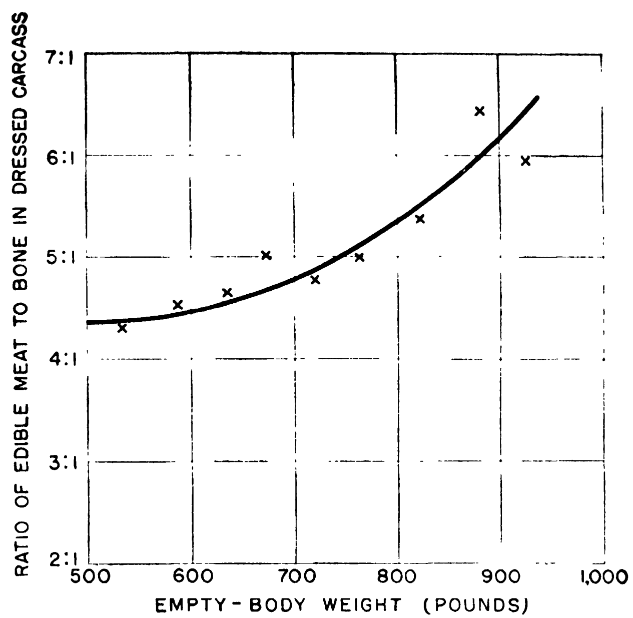


Figure 10.—Fatness of "eye" muscle increases more and more rapidly as the fatness of the dressed carcass of high-grade yearling Hereford steers increases from approximately 13 to 33 percent. (Based on unpublished data of the Michigan Agricultural Experiment Station and the U. S. Bureau of Animal Industry.)

PROPORTION OF EDIBLE MEAT

The proportion of edible meat in the animal body or in the dressed carcass is one of the most interesting and significant of the factors which reflect growth and fattening of the animal. It is important not only from the scientific point of view but to all branches of the livestock and meat industry. Moreover, it directly concerns every

Figure 11.—Ratio of edible meat to bone increases more and more rapidly as the empty-body weight of high-grade yearling Hereford steers increases from approximately 500 to 935 pounds. Crosses represent averages for the steers as grouped at 50-pound intervals of empty-body weight. (Based on unpublished data of the Michigan Agricultural Experiment Station and the U. S. Bureau of Animal Industry.)



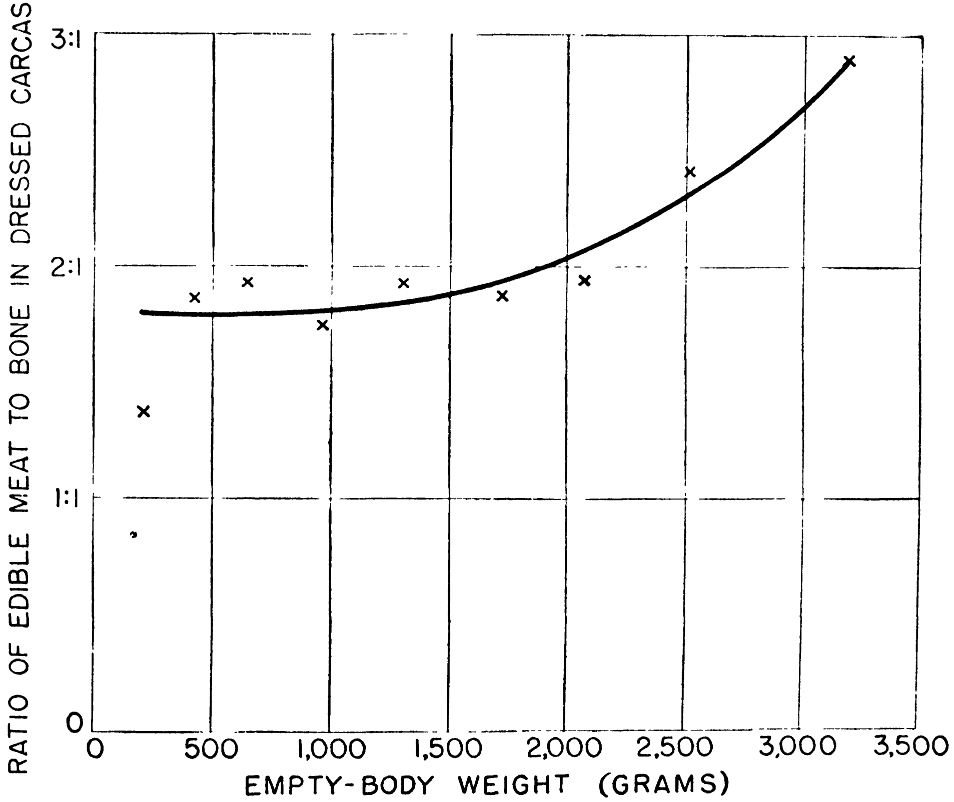


Figure 12.—Ratio of edible meat to bone increases more and more rapidly as the empty-body weight of White Plymouth Rock cockerels increases from approximately 200 to 3,200 grams, or the live weight from approximately 0.5 pound to 7 pounds. Crosses represent averages of the several weight groups considered. (Based on data from Illinois Agricultural Experiment Station Bulletin 278 (797).)

person or family purchasing and consuming a cut of meat. It goes almost without saying that the proportion of edible meat or, more specifically, the ratio of meat to bone in the chop, steak, or roast, and therefore in the dressed carcass or entire body, is a matter that commands and receives basic consideration. With fatness, which of course also has a definite bearing on the proportion of edible meat, this factor plays a large part in determining the economy of meat purchases.

Figures 11 and 12 illustrate changes in this factor that have been observed in cattle and chickens, respectively. It is interesting that in both cases the relation between ratio of edible meat to bone in the dressed carcass and weight of empty body is represented by a curved line, indicating that at heavier weights the relative rate of increase in the proportion of edible meat was much greater than at lighter weights. Of course, it is rather generally recognized that fattening, as distinct from growth, plays a large part in this. The importance of fat is well illustrated by figure 13, in which it will be noted that the increase in weight of fat from the analyzed side of steer cattle is only slightly less rapid than the increase in weight of edible meat. These changes are associated with growth and fattening and represent an increase in the ether-extract content of the analyzed side from approximately 13 to 33 percent.

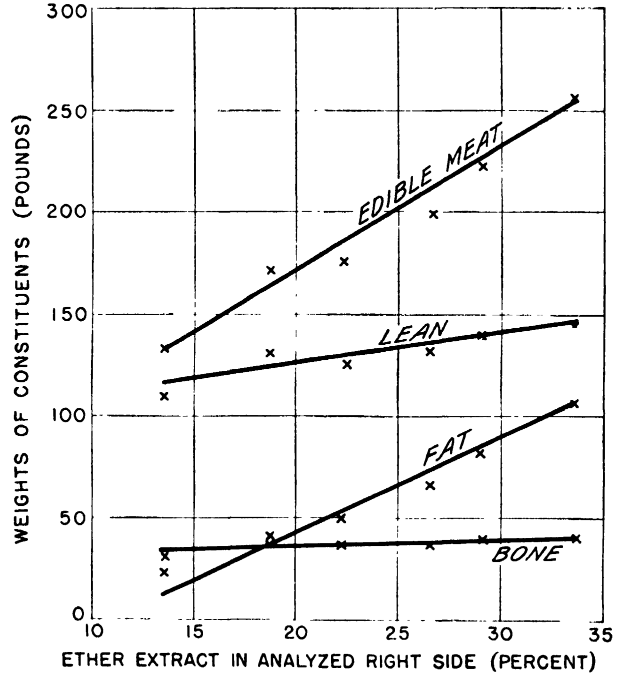


Figure 13. — Comparative increases in weights of edible meat, lean, fat, and bone from the right side of high-grade yearling Hereford steers, associated with growth and fattening represented by increase in ether-extract content of from approximately 13 to 33 percent. Crosses represent averages for 4-percent intervals of ether-extract content of analyzed right side. (Based on unpublished data of the Michigan Agricultural Experiment Station and the U. S. Bureau of Animal Industry.)

Further examination of figures 11 and 12 shows that associated with the indicated increases in empty-body weight was an increase of approximately 50 percent in the ratio of meat to bone in cattle and of approximately 55 percent in chickens.

MEASURING THE EFFICIENCY OF UTILIZATION OF FEED FOR GROWTH[7]

The need for a simple but accurate method of measuring and comparing the efficiency with which animals utilize feed for growth has been recognized for a long time. Such a method would be of great value to both the geneticist and the nutritionist. The geneticist could use it as an aid in selecting strains of the different meat-producing animals that would be more efficient than the average in converting animal feed into human food, and the nutritionist could use it for comparing the growth-promoting and other values of different diets or rations.

Various methods of measuring the efficiency of utilization of feed for growth have been proposed, but most of them are of restricted applicability and some are too complicated for practical use. A method that offers much promise was developed from the growth studies of Titus, Jull, and Hendricks (*1143*) and has been discussed recently by Lambert, Ellis, Black, and Titus (*657*). In applying this method, the data of the ordinary feeding experiment may be used, but the best results are obtained only when the utmost care is exercised in measuring the feed consumption and the resulting gains in live weight.

This method is based on the fact that the equation of the curve of diminishing increment expresses with a high degree of accuracy the relationship between live weight and feed consumption, a fact which was first pointed out by Spillman (*1095*). The equation of the curve of diminishing increment, as applied to the relationship, may be written—

$$w = A - Be^{-kf} \qquad (1)$$

in which

w is the live weight after any quantity of feed, f, has been consumed;
A is the maximum live weight attainable as a result of growth, but not as a result of fattening;
B is the total gain in live weight that is made in reaching the maximum live weight;
e is the base of the natural system of logarithms;
k is a constant which is a measure of the rate of decrease in the efficiency of feed utilization; and
f is the quantity of feed that is required for attaining any live weight, w.

The first derivative of equation (1) is

$$\frac{dw}{df} = kA - kw \qquad (2)$$

Obviously, $\frac{dw}{df}$ may be defined as the efficiency (E) of feed utilization for growth, because it represents the gain in live weight per unit weight of feed consumed. If for simplicity, E is written in place of $\frac{dw}{df}$ and c in place of kA, equation (2) becomes—

$$E = c - kw \qquad (3)$$

in which

E is the efficiency of feed utilization for growth, i. e., the gain in the live weight per weight unit of feed consumed;
c is the maximum efficiency of feed utilization for growth;
k is a measure of the rate of decrease in the efficiency of feed utilization; and
w is the live weight at which the efficiency of feed utilization is being measured.

Inasmuch as $E = c - kw$ is an equation of a straight line, it may be written—

$$\overline{E} = c - k\frac{(w_1 + w_2)}{2} \qquad (4)$$

or

$$\overline{E} = c - k\overline{w} \qquad (5)$$

in which

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[7] The following pages are intended primarily for students and others interested in the technical aspects of the subject.

$\bar{E}$ is the average efficiency of feed utilization while the live weight is changing from w_1 to w_2 as a result of the quantity of feed $(f_2 - f_1)$ having been consumed;

c and k have the same significance as before, and

$\bar{w}$ is the average of any two live weights, such as w_1 and w_2.

The usual method of dividing the total gain in live weight by the total weight of feed consumed yields a measure of the average efficiency of the utilization of the feed for growth; but it must be recognized that this average value gives no indication of how the efficiency changed during the period the feed was being consumed. Thus, two animals may be equally efficient in their use of feed at one age but very unlike at some other age. However, the method presented here permits determination of (1) the initial efficiency, i. e., the efficiency when the first feed was eaten, (2) the rate at which the efficiency decreased as the live weight increased, and (3) the efficiency at any live weight within the range for which data were obtained.

In order to apply the method it is necessary to have the following data: (1) The live weights of an animal, or group of animals, obtained at appropriate intervals, the number of which should be as large as possible, preferably not less than seven or eight; and (2) the cumulative weights of feed consumed up to each time the animal, or group of animals, was weighed.

A typical set of data is given below:

Live weight, w	Cumulative feed consumption, f
Pounds	*Pounds*
6. 5	0. 0
11. 4	12. 7
18. 6	31. 6
26. 0	55. 9
32. 8	83. 1
38. 7	112. 2
42. 3	143. 0

The first step is to compute the average weights and the average efficiencies. This is done as follows:

$\bar{w}$, the average weight, or $\frac{w_2 + w_1}{2}$	$\bar{E}$, the average efficiency, or $\frac{w_2 - w_1}{f_2 - f_1}$
8. 95	0. 3858
15. 00	. 3810
22. 30	. 3045
29. 40	. 2500
35. 75	. 2027
40. 50	. 1169

The numerical measures of efficiency of feed utilization are then estimated by the method of least squares, as indicated in table 5.

TABLE 5.—*Estimation of the values of c and k by the method of least squares*

a	*b*	*l*	*s*	*bb*	*bl*	*bs*
	(w)	$(\bar{E})$				
1	8. 95	0. 386	10. 336	80. 1025	3. 45470	92. 50720
1	15. 00	. 381	16. 381	225. 0000	5. 71500	245. 71500
1	22. 30	. 305	23. 605	497. 2900	6. 80150	526. 39150
1	29. 40	. 250	30. 650	864. 3600	7. 35000	901. 11000
1	35. 75	. 203	36. 953	1, 278. 0625	7. 25725	1, 321. 06975
1	40. 50	. 117	41. 617	1, 640. 2500	4. 73850	1, 685. 48850
6 or $(aa)_1$	151. 90 or $(ab)_1$	1. 642 or $(al)_1$	159. 542 or $(as)_1$	4, 585. 0650 or $(bb)_1$	35. 31695 or $(bl)_1$	4, 772. 28195 or $(bs)_1$

Checks: $(aa)_1+(ab)_1+(al)_1=(as)_1$ and $(ab)_1+(bb)_1+(bl)_1=(bs)_1$.

$$(bb)_2=(bb)_1-\frac{(ab)_1}{(aa)_1}(ab)_1=4{,}585.0650-\frac{151.90}{6}\times 151.90=739.4633.$$

$$(bl)_2=(bl)_1-\frac{(ab)_1}{(aa)_1}(al)_1=35.31695-\frac{151.90}{6}\times 1.642=-6.253016.$$

$$k=\frac{(bl)_2}{(bb)_2}=\frac{-6.253016}{739.4633}=0.008456.$$

$$c=-\frac{(ab)_1}{(aa)_1}k+\frac{(al)_1}{(aa)_1}=0.21408+0.27366=0.48774.$$

The standard errors of c and k may now be computed. The numerical values of c and k, which have just been obtained, are substituted in the equation, $\bar{E}=c-k\bar{w}$, yielding the equation, $\bar{E}=0.488-0.00846\,w$, from which values of $\bar{E}$ may be calculated by inserting the values of w given in the second tabulation on page 466. The subsequent computations are indicated in table 6.

TABLE 6.—*Estimation of the standard errors of c and k*

E_{observed}	$\bar{E}_{\text{calculated}}$	$E_o-\bar{E}_c$	$(\bar{E}_o-\bar{E}_c)^2$	E_{observed}	$\bar{E}_{\text{calculated}}$	$E_o-\bar{E}_c$	$(\bar{E}_o-\bar{E}_c)^2$
0.3858	0.4121	−0.0263	0.00069169	0.2027	0.1854	+0.0173	0.00029929
.3810	.3609	+.0201	.00040401	.1169	.1453	−.0284	.00080656
.3045	.2992	+.0053	.00002809				
.2500	.2391	+.0109	.00011881	Total			.00234845

$$s^2=\frac{\Sigma(\bar{E}_o-E_c)^2}{n-u}=\frac{0.00234845}{6-2}=0.0005871125.$$

n is the number of observations used in obtaining the values of k and c (6 in this case); and u is the number of constants in the equation, $E=c-kw$ (2 in this case).

$$\text{Standard error of } k=\sqrt{\frac{s^2}{(bb)_2}}=\sqrt{\frac{0.0005871125}{739.4633}}=\sqrt{0.000000793971}=0.000891.$$

$$\text{Standard error of } c=\sqrt{\frac{s^2}{\frac{(bb)_2(aa)_1}{(bb)_1}}}=\sqrt{\frac{0.0005871125}{0.96765912}}=\sqrt{0.0006067348}=0.02463.$$

Thus we have:

$c=0.488\pm 0.025$, and
$k=0.00846\pm 0.00089$.

The initial efficiency, which is the efficiency when the first feed is fed, is computed by inserting the live weight at the time of the first feeding in place of w in the equation $E=c-kw$. In the present example we get:

$E_{\text{initial}}=0.488-0.00846\times 6.5=0.433.$

ESTIMATING COMPOSITION

In most instances, the results of a study on growth or fattening cannot be regarded as complete unless they include information on the composition of the animal body, or at least of the dressed carcass. Measuring growth or fattening in terms of live weight or by the determination of such characteristics as height, width, length, and girth of the animal is at best an indirect method and furnishes only a rough approximation of the nutritive value of the meat animal. However, the analysis of the entire body or carcass chemically, or even physically, is time-consuming and expensive. For that reason many research workers are interested in short cuts or in simplified methods that will enable them to estimate composition, or certain factors thereof, with satisfactory accuracy. A number of investigators, recognizing this interest and need, have worked on the problem, and several methods of this nature have been developed. Examples are presented below.

Lush (*699*) reported that the relation between the fat content of the entire live animal and the dressing percentage in steers was represented by a correlation coefficient of +0.84. The estimating equation was found to be as follows: Percentage of fat in entire live animal equals 1.782 times dressing percentage minus 86.40.

It was also reported by Lush that in steers the relation between the fat content of the entire live animal and the percentage of caul fat based on live weight was represented by a correlation coefficient of +0.89, with the relation between the percentage of bone in the dressed carcass and the percentage of leg bones based on live weight represented by the coefficient +0.95. In the former instance the estimating equation was: Percentage of fat in entire live animal equals 14.55 times percentage of caul fat based on live weight plus 5.19. The equation in the latter instance was as follows: Percentage of bone in dressed carcass equals 0.04 plus 10.22 times percentage of leg bones based on live weight.

Warner, Ellis, and Howe (*1182*) determined that in hogs the relation between the percentage of fat in the edible portion of the dressed carcass and the combined weight of the cutting fat (leaf fat, skinned fat from trimmings, and skinned back fat) and belly, expressed as a percentage of the weight of the entire cold dressed carcass, was represented by the correlation coefficient +0.91. The following equation was developed: Percentage of fat in edible portion of carcass equals 5.57 plus 1.54 times percentage of cutting fat and belly based on carcass weight.

Hankins and Ellis (*470*) found the percentage of fat in the edible portion of the carcasses of hogs and the average thickness of back fat to have a correlation coefficient of +0.84, and developed the following equation for estimating the former: Percentage of fat in edible portion of carcass equals 22.45 plus 0.691 times average thickness of back fat, in millimeters.

Workers in the Bureau of Animal Industry found[8] a correlation of +0.98 between the fat (ether extract) content of the edible portion of dressed lamb carcasses and the percentage of the same component of the edible portion of nine-rib cuts from such carcasses. The same correlation value was found to represent the relation between the separable-fat content of lamb carcasses and the separable-fat content of the nine-rib cuts from such carcasses. The respective equations developed are as follows: Percentage of fat (ether extract) in edible portion of carcass equals 3.58 plus 0.73 times percentage of fat, or ether extract, in edible portion of nine-rib cut; and percentage of separable fat in carcass equals 4.28 plus 0.72 times percentage of separable fat in nine-rib cut.

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[8] Results unpublished.

SOME EFFECTS OF NUTRITIONAL LEVELS

by Paul E. Howe

THE different parts of the body develop at quite different rates at different periods in an animal's life. By raising or lowering the general level of nutrition, it is apparently possible to vary these rates considerably, producing animals with very different characteristics. This explains the production of "bacon type" and "lard type" hogs from animals with the same genetic constitution. Here is a brief account of new experimental work on this line which is significant for livestock producers.

ADEQUATE nutrition is necessary to the full development of the inherited characteristics of animals (and man also, of course). Various factors other than accident or disease interfere with or modify the inherited possibilities of an individual. Development may be modified to a considerable degree by nutrition; hereditary defects may interfere with the utilization of food, although physical development may become normal when these defects are overcome; good nutrition may mask hereditary characteristics or defects; psychological, physiological, or pathological conditions may interfere with the taking of food or its utilization.

The kind and rate of feeding has such a marked influence on the physical development of animals that it is necessary to define normal growth and physique before attempting to discuss the modifying effects of nutrition. In man, the objective of good nutrition is a strong healthy body capable of meeting the vicissitudes of a long life. The requirements for domestic animals, on the other hand, vary according to the purposes for which they are kept. Long life and good reproductive ability are important factors in animals used to replenish their respective species. Such animals are also used for productive purposes—for example, cows and goats for milk production, sheep for wool production, and horses for work. For animals that are fattened for food, however, long life is not so important as is the rapid development of flesh—muscle and fat.

The growth and development of the body, as measured in terms of

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[1] Paul E. Howe is Chief, Animal Nutrition Division, Bureau of Animal Industry.

height and weight, is a fairly regular process, accelerated shortly before birth and at the time of puberty, with a gradual slight regression during adult life. The development, however, is a composite of changes that occur at different rates in different parts of the body. Certain parts develop earlier than others. The results of work in Cambridge, England,[2] indicate that the various tissues and anatomical parts of the body have a definite order and proportion in development. The limbs develop relatively early, with the fore limbs developing slightly earlier than the hind limbs. The latest development occurs in the middle of the back. There is a marked differential growth of the skeleton, muscle, and fat. The skeleton makes a greater proportion of its growth earlier in life than does muscle, and muscle earlier than fat. There are likewise differential growth relationships in these tissues. In the skeletal units the direction of development is from the head to the trunk. The bones of the limbs develop from the feet toward the body. Muscle and fat surrounding the various skeletal units show a similar type of differential growth, and develop latest over the loin. The body organs show a marked differential growth; the parts essential to life processes and body functions are relatively well developed at birth and make a smaller proportion of growth after birth than the less essential tissues. The organs that function primarily or largely as stores of nutrients, such as muscle and fat, show little development until the later stages of growth.

The nutritional status of the body determines to a considerable extent the rate of development. Abundant nutrition permits the maximum expression of inherited characteristics, while undernutrition results in retarded development. An interesting example of the effects of different rates of feeding is shown in some experiments of McMeekan and Hammond on the development of swine fed in different ways to the same final weight.

Young pigs of similar breeding were individually fed the same feed in such a way that they gained weight at predetermined rates until they weighed 200 pounds, as follows: (1) Rapidly throughout (high-high); (2) rapidly at first, then slowly (high-low); (3) slowly at first, then rapidly (low-high); and (4) slowly throughout. Up to 16 weeks of age there were 2 groups, low plane (3 and 4 above) and high plane (1 and 2 above), which were then divided to give a rapid and a slow rate of gain for animals selected for each group. The plan of experiment and rates of gain are given in figure 1. When the pigs were 16 weeks old a certain number of the animals were slaughtered and the weights of the organs, of various anatomical parts, and of the muscle, fat, and bone of the parts were determined. Similar observations were made when the remaining animals reached 200 pounds body weight.

The following summary of McMeekan and Hammond's work indicates the effect of variation in rate of development on the characteristics of the pigs and the possibilities of modifying body characteristics by changes in nutrition:

> By making the growth curve rise quickly (high plane) instead of slowly (low plane) certain parts and tissues of the body are made to develop more quickly

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[2] Unpublished results of C. P. McMeekan and John Hammond. Presented in part by McMeekan in the Proceedings of the American Society of Animal Production, 1938. Data presented here with the permission of Professor Hammond.

than others. For example at 16 weeks old (fig. 2) the weight of the loin in the high-plane pigs was 450 percent of that in the low-plane pigs, while the weight of the head was only 209 percent. Similarly the weight of the fat in the high-plane pigs was 1,007 percent of that of the low-plane pigs, while the weight of the bone was only 224 percent (fig. 3). This is equally true when the pigs are compared at the same body weight (200 pounds; high-high and low-low groups)

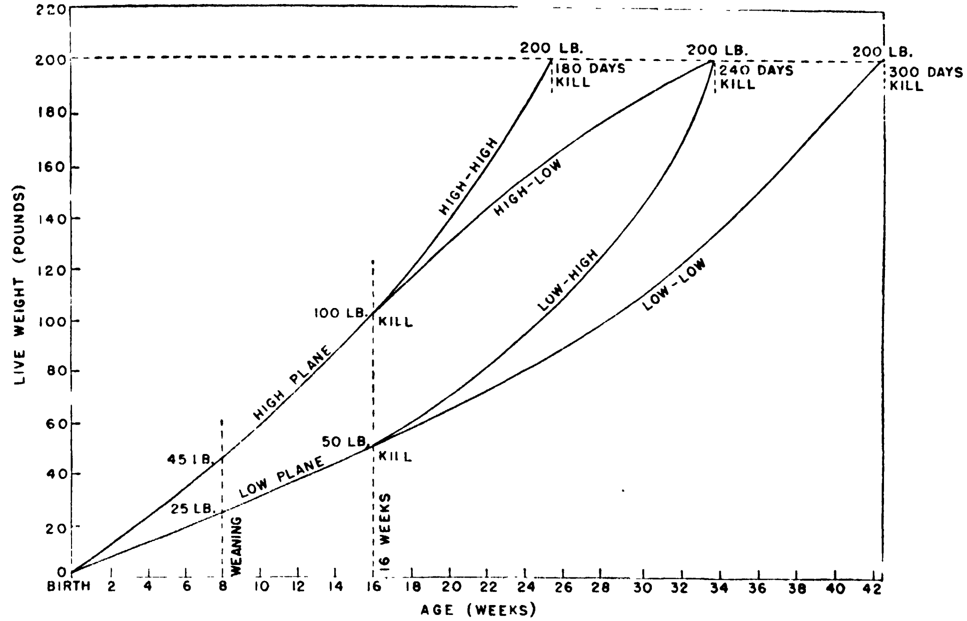

Figure 1. Plan of the experiment described in the text. Growth curves of pigs fed at different nutritional levels to the same final body weight.

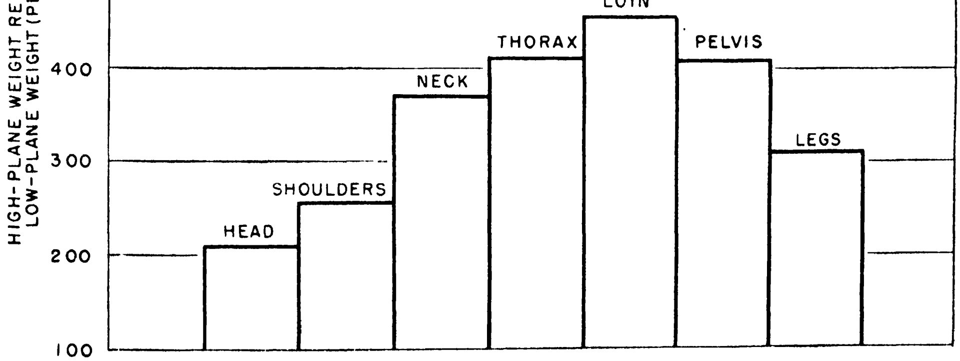

Figure 2.—How the body proportions of the pigs on the different levels of nutrition varied at 16 weeks of age. Taking low-plane weights as 100 percent, the weights of the different body parts of pigs on the high plane exceeded them as shown.

as well as at the same age. If the degree to which the different parts and tissues of the body are affected by the quick rise is compared with that resulting from the slow rise in the live-weight growth curve, it is found that these correspond to the order in which the parts and tissues develop as the pig grows. Thus, those parts and tissues which, like the loin and the fat, develop late in life are increased to a much greater degree by a high plane of nutrition (quickly rising growth curve) than are those parts and tissues that develop early in life, such as the head and the bone. The reason for this is probably that the latter have the greatest metabolic rate and so have priority over the later developing tissues when the supplies of nutrition are low.

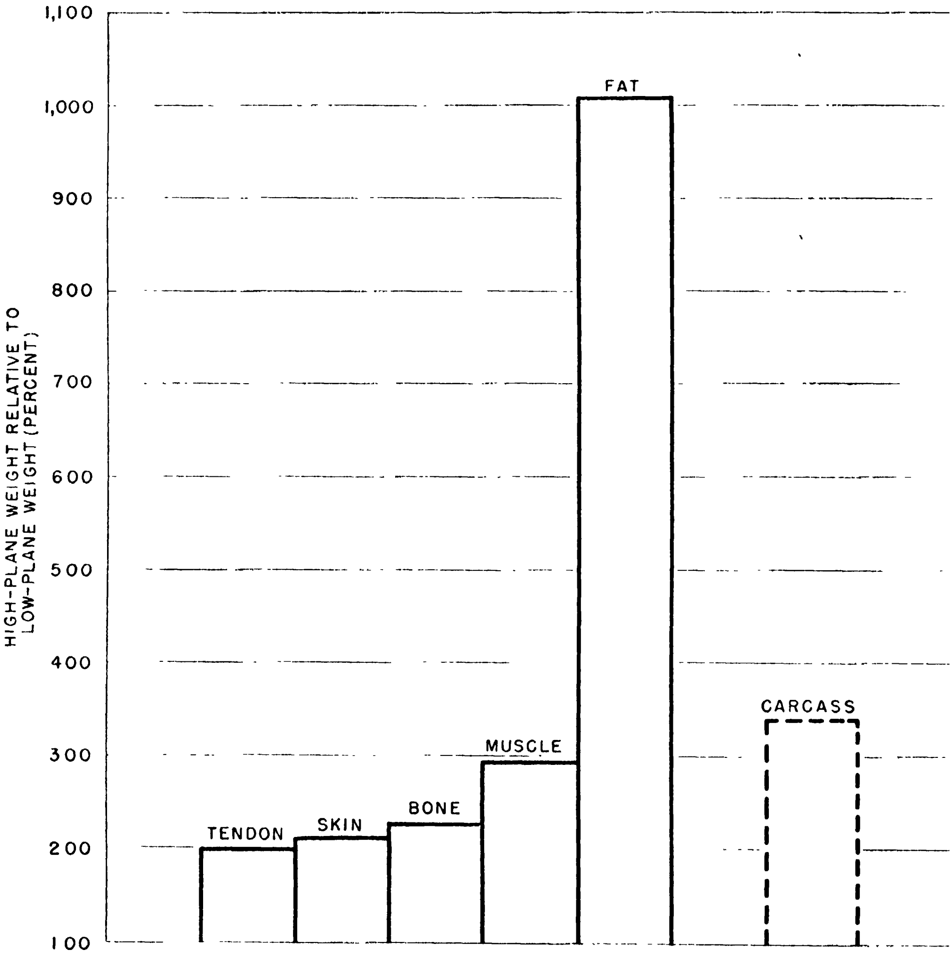

Figure 3.—How the carcass composition of the pigs varied at different levels of nutrition at 16 weeks of age. Low-plane weight taken as 100 percent.

By making growth rapid early in life and slowing it down later (high-low group) the early developing parts and tissues of the body are accentuated and the later developing parts and tissues are reduced. Conversely, by slowing growth early in life and speeding it up later (low-high group), the later developing parts and tissues of the body are accentuated and the early developing parts and tissues are reduced. Thus one can produce experimentally at the same age and same body weight, by controlling the shape of the growth curve, a bacon type (high-low) or pork type (low-high) from the same strain of pig (figs. 4, 5, and 6).

The results of the four differently shaped growth curves on the composition of the carcass at 200 pounds are summarized in table 1.

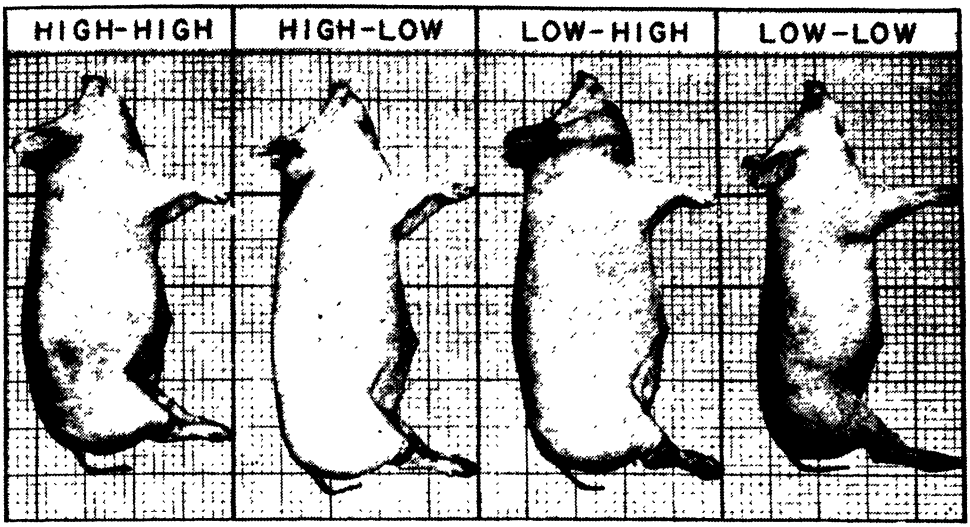

Figure 4.—Body proportions at 200 pounds, arranged at the same shoulder height.

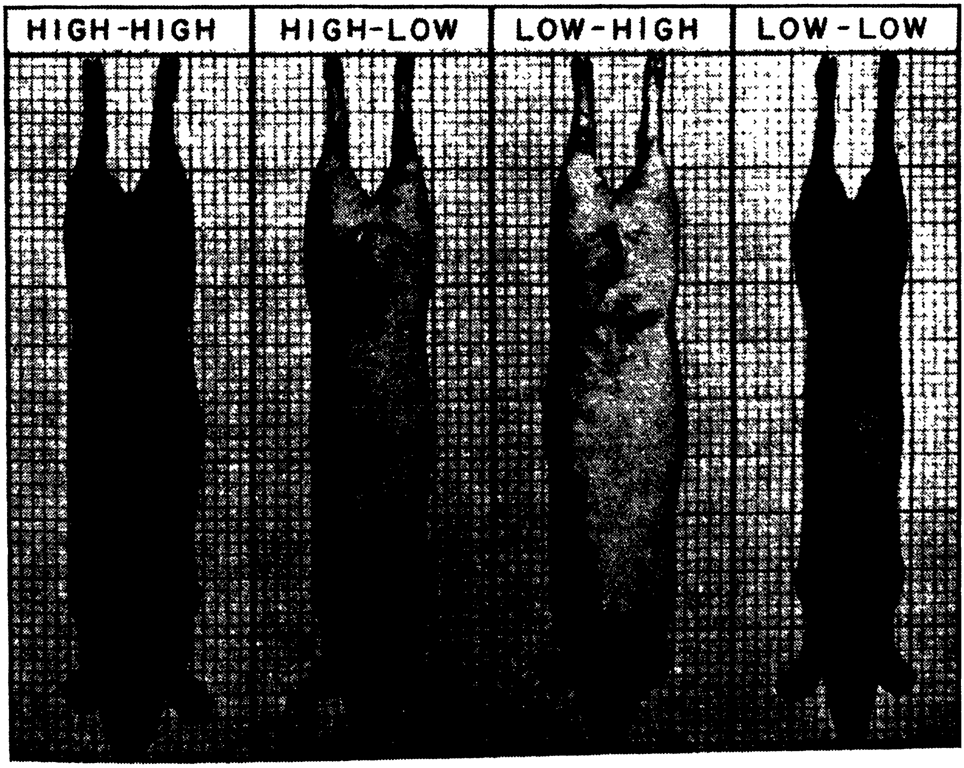

Figure 5.—Body proportions at 200 pounds, arranged at the same total length.

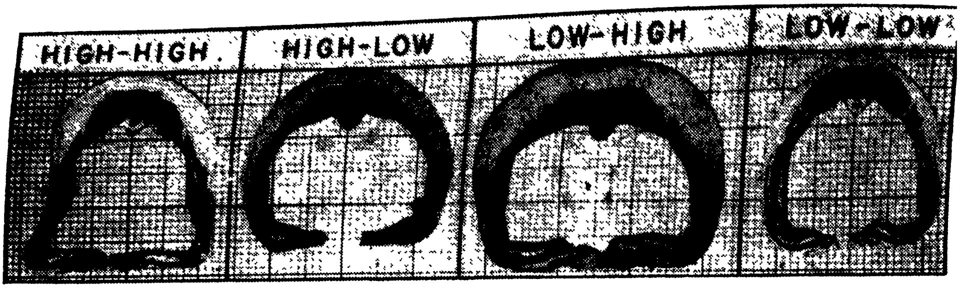

Figure 6.—Loin cut at the last rib at 200 pounds, arranged at the same eye-muscle length.

TABLE 1.—*Results of four different growth curves on composition of the carcass of hogs weighing 200 pounds*

Treatment	Proportion of carcass weight				
	Fat	Muscle	Bone	Skin	Tendon, gland, etc.
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
High-high	38.3	40.3	11.0	5.3	5.1
High-low	33.4	44.9	11.2	5.4	5.1
Low-high	44.1	36.3	9.7	4.8	5.1
Low-low	27.5	49.1	12.4	5.8	5.2

Under the practical conditions of animal production, meat-producing animals are reared under all the four systems of nutrition represented by the growth curves described. Thus the lard type of pig is reared under a low-high system and yields a high proportion of fat and a low proportion of muscle in the carcass, while the bacon type is reared on a high-high or high-low system and yields a carcass with more muscle and less fat.

EFFECTS OF UNDERNUTRITION AND EXERCISE

Undernutrition has its most pronounced effect first on the less essential portions of the body. The skeleton and essential organs continue to grow at the expense of muscular tissue and fat. A similar effect is produced by fasting, when the body draws primarily upon muscle tissue and fat to maintain the functional organs. This reserve of material, represented particularly by the muscle, fat, and bones, plays an important role in a period of undernutrition or drain upon the body tissues. Examples of the utilization of body reserves during certain periods of the year are found in the case of wild and hibernating animals or domestic animals in winter or drought. The ability to draw upon the body reserves is often shown during reproduction and lactation, especially the latter. Even though the diet is inadequate, the fetus grows and milk is produced at the expense of the mother. In the case of the modern high-producing dairy cow, careful feeding is necessary to keep her from drawing upon her reserves. In fact, it has been suggested that many animals are unable to meet their calcium requirements during the period of lactation even though well fed, but that these reserves are restored between lactations.

The occasional moderate utilization of body reserves is not detrimental, since they are readily replenished when food is again available or the temporary drain is removed. An interesting example of periodical drain and replenishment is seen on the range, where cattle go through the winter like wild animals, reproducing and often beginning lactation on restricted feed and replenishing these losses during the remainder of the year.

The results of Hammond's experiments on the effect of different planes of nutrition on the development of pigs also apply to other animals that are relatively inactive. With man or with active animals such as the horse and dog, exercise modifies the potential effect of a liberal diet in that the activity diverts the energy contained in the food away from the formation of fat. Under such conditions the body tends to develop muscle and bone without excessive fattening. The quantity of food required to cover exercise was illustrated in an experiment planned to show the effect of exercise on the quality of meat produced by steers. To remove the effect of fattening on the quality of the meat, it was necessary to feed the two groups so that the weight of pairs of exercised and unexercised animals would be the same. At one stage of the experiment the exercised cattle required roughly 8 pounds of grain a day more than the unexercised cattle to maintain the same body weight.

NUTRITION AND LONGEVITY

Recent experiments have raised the question of the best level of nutrition for a long life, compatible with health. Length of life and maximum rate of growth are not necessarily related. Certain experimental results with rats indicate that the reverse may be true. Rats fed a diet adequate in proteins, vitamins, inorganic salts, and fats but restricted in calories lived longer on the average than those fed the same basal diet with an unlimited intake of calories. The males on the restricted diet lived roughly one-third longer than the well-fed rats, while the females lived a little longer than the female controls. About one-third of the rats on the restricted diets lived to the age of 1,200 days, which is equivalent to approximately 120 years in man. In these experiments the females were not allowed to reproduce. While the rats on the restricted diet lived longer, they did not attain as great a body weight as the full-fed rats and the bones were lighter and more fragile. Animals on restricted diets had adequate amounts of the protective foods.

Other experiments on the influence of diet on longevity indicate that a diet that has given satisfactory results with regard to growth, reproduction, and lactation may be improved by enrichment in certain factors, including vitamin A.

THE RELATION OF DIET TO REPRODUCTION

FOR many centuries it has been a matter of great importance to farmers to have fertile livestock. In the old days, there were magic ceremonies to prevent infertility. Today farmers call on science. These authors discuss the many possible causes of infertility, with special emphasis on shortcomings in the diet. They conclude that in spite of considerable research, some of the remedies of today are not much more truly scientific than the methods of the magicians.

REPRODUCTIVE FAILURES IN LIVESTOCK

by Ralph W. Phillips [1]

REPRODUCTIVE failures in livestock may be due to a number of factors and may occur at any of several points during the reproductive process. The occurrence of infertile matings is from 20 to 50 percent under conditions of good nutrition, management, and sanitation. This is true of laboratory animals as well. Thus there is room for considerable improvement in reproductive efficiency; but most of the existing data serve only to indicate the extent of the problem, and relatively little information is available that gives help in indicating how the present results may be improved. It should be remembered, when studying this problem, that the use of medicinal, nutritional, or other therapeutic measures to correct the trouble may not be desirable where the sterility or low fertility may be demonstrated to have a hereditary basis. If offspring of such treated animals were saved for breeding, they would pass on their defects, and reproductive difficulties as well as the need for therapeutic measures would tend to increase.

The problem should not be disregarded, in spite of the many difficulties that confront those who attempt to solve it. A wide field of research is open in determining the relative importance of the factors that contribute to reproductive failures. Such studies, if they are to be of real value, must include careful observations on the breeding history of the animals involved, complete data on all observable factors and post-mortem examination of a large number of cases. They must also include studies of control animals with good breeding records. Sufficient numbers, proper experimental design, and careful analysis are essential, and such studies will necessitate cooperation among physiologists, pathologists, nutritionists, geneticists, and perhaps others if the most effective work is to be done. When the contributing causes are known, investigation of indicated therapeutic measures, whether they be medicinal, nutritional, endocrine, or of some other type, will naturally follow, and the breeder can look with increased hope to the betterment of the breeding efficiency of his animals.

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[1] Ralph W. Phillips is Physiologist, Animal Husbandry Division, Bureau of Animal Industry.

CAUSES OF REPRODUCTIVE FAILURES

Failures in reproduction occur frequently in all classes of livestock, in the form either of permanent or temporary sterility or of lowered fertility. The cases of lowered fertility and temporary sterility are probably more important causes of loss than those of complete sterility, since the latter are soon noted and eliminated. On the other hand, a male or female of reduced fertility or with recurring periods of temporary sterility may be retained for years and reduce the breeding efficiency of the entire herd or flock. This is especially true of males that are able to settle the females but require a large number of services per pregnancy.

The immediate causes of these failures may be (1) physiological, (2) genetic (hereditary) (3) pathological, (4) anatomical, including congenital defects of the reproductive tract and obstructions due to injury or disease, (5) mechanical injury to the reproductive tract or the fetus during pregnancy, or (6) nutritional; or there may be a combination of causes. The normal course of the reproductive process may be interrupted at any of several points owing to (1) failure to form spermatozoa or ova, or a reduction of the number or quality of germ cells produced, (2) failure of animals to copulate owing to lack of sexual desire or to injury, (3) death of the liberated ova or spermatozoa before fertilization, (4) failure of fertilization, (5) failure of implantation in the uterus, (6) failure of normal embryonic and fetal development, and resorption or abortion, and (7) stillbirth at the end of a normal term.

It should be evident that the diagnostician must proceed with great care if the specific cause of reproductive failure in any one case is to be accurately determined. In many instances it is impossible to separate the causes of infertility into well-defined classes. Apparent physiological disturbances may be due to pathological conditions or genetic causes. The occurrence of pathological conditions may be associated with inherited differences in resistance to infection or with inadequate nutrition. Anatomical defects of certain types are often inherited.

Many of the available data give information on the total number of reproductive failures but little on the immediate or basic causes of the infertility. Many data have been taken from census figures, registration records, and questionnaires and surveys, and these are useful in giving some indication of the acuteness of the problem but of little value in locating causes. The latter information is essential if data are to be of value in indicating methods of increasing fertility.

OCCURRENCE OF REPRODUCTIVE FAILURES

Before reviewing available information on the occurrence of reproductive failures in livestock it should be pointed out that the problem is not limited to farm animals, but that there is a considerable proportion of infertile matings in laboratory animals kept under well-controlled conditions. For example, Hammond and Marshall (*467*)[2] reported 31.1 percent of sterile matings in 312 rabbit does that had not been pregnant recently, while only 1 or 2 cases of infertile matings were observed in several hundred where mating occurred just after parturition or at the end of pseudopregnancy. These findings are in general agreement with those of Kellogg (*614*) and Friedman (*396*). In rats carefully selected as being in estrus, or heat, Evans and Bishop (*345*) report 84 percent of fertile matings, and Mendel and Hubbell (*783*) report yearly averages of 86, 65, 68, and 93 percent of fertile matings in a colony for the years 1912, 1919, 1925, and 1935, respectively. The high percentage in the last year was attributed to an improved, and very expensive, diet. Wright (*1273*) states that in guinea pigs, an estrus period follows parturition, and that 50 to 60 percent of the matings at this time in a vigorous stock are fertile.

Studies by three agencies in England have shown that more animals are discarded from dairy herds because of reproductive troubles than for any other reason, the percentages being 19.3, 26, and 23.7.

In a study of the results of breeding a large number of dairy and beef cattle in Maine, Gowen (*428*) found that 78 percent became pregnant at the first service, 15 at the second, 4 at the third, while 3 percent required further services or were infertile.

The problem in range areas is more difficult to evaluate because of the lack of individual breeding records. The common method of evaluating breeding success in such herds is to determine the percentage of calves born to each 100 cows in the herd at breeding time. Data from 16 different sources show a range of from 40 to 77 percent in different sections of the western range area, with an average of 63. The calf crops on individual ranches included in these reports ranged from 25 to 95 percent.

The importance of the bull as a cause of reproductive failures is often underestimated. Williams and Savage (*1231*) observed 276 herd bulls, of which 198 had known breeding records. Of these, 34 percent had poor breeding records as judged by the services required per pregnancy. Lagerlöf (*656*), who investigated the causes of early disposal of 2,313 bulls in Sweden, states that 24 percent were discarded because of reproductive failures in one form or another and indicates that the number of cases of incapacity to copulate surpasses those due to incapacity to fertilize.

The incidence of sterility is usually higher in horses and jack stock than in other classes of livestock. Robinson (*974*) investigated the results of a large number of matings of horses in which all the stallions were certified as being healthy. Of 28,241 Clydesdale mares bred to 390 stallions during a 6-year period, only 52 percent produced foals. Of 3,640 thoroughbred mares bred to 43 stallions during a 5-year period, only 42.3 percent produced foals. Hammond (*465*) found an average foaling percentage of 59 percent in draft mares bred to 358 premium stallions in the British Ministry of Agriculture's livestock scheme. Unpublished data collected by Ewing in Missouri show that of 2,895 mares bred, 55 percent appeared to be settled and 45 percent produced foals. Kern (*622*) presents census figures showing that the percentages of mares bred that produced foals in Germany during 1932–35 were 56, 57, 55, and 52. In Rhineland horses the average was 61 percent in 1936, which was considered satisfactory. The number of matings per mare is not specified, but it is assumed that in many of the above cases mares were bred at more than one heat period. The problem of low fertility is perhaps even more acute in jack stock where experienced breeders do not expect more than 40 percent of the jennets bred during a season to produce colts.

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[2] Italic numbers in parentheses refer to Literature Cited p. 1075.

Fertility in sheep is commonly expressed in terms of the percentage of lambs born to each of 100 ewes bred in one season. The size of the lamb crop will vary with the breed and with the environment. Nichols (*858*) reports a lamb crop of 154 percent for 1,033 ewes, kept under farm-flock conditions, that were flushed (fed heavily before breeding), and 140 percent for 4,054 ewes that were not flushed. Lamb crops of 164 and 143 percent, respectively, were reported by Mohler (*805*) for similar conditions. Under range conditions the percentages are much lower, ranging from 70 to 80 percent in different sections. Figures of this type give no direct information on the proportions of ewes that fail to produce lambs or of rams that are low in fertility or sterile.

Polovtseva et al. (*930*) state that in the Union of Soviet Socialist Republics sterility in sheep averages about 6 percent and is as high as 15 to 20 on some farms. These figures apparently indicate the proportion of ewes that fail to produce offspring each year. Richter (*962*) reports about 5 percent sterility in goats and 10 percent in sheep each year in Germany and Hungary.

Examination of breeding records of the Bureau of Animal Industry's flock at Beltsville, Md., for a 10-year period shows the average number of services required per pregnancy in four breeds to be as follows: Hampshire, 2.5; Karakul, 1.4; Shropshire, 2.9; and Southdown, 2.9.

Since swine produce a number of young at one time, estimates of fertility are more difficult to evaluate than in those species producing only one or two per litter. Examination of the breeding records of 250 sows selected at random in the Bureau of Animal Industry's herd at Beltsville, revealed that 42, or 16.8 percent, failed to produce litters. Of the remaining 208, 84 percent required only one service, 12 required two services, 2.5 required three, and 1.5 percent required four. Of the 42 that failed to produce litters, 25 were bred once and the remaining 17 from two to five times. Many of these were apparently settled, as judged by failure to return in estrus during the breeding season, but failed to produce litters.

RELATIVE IMPORTANCE OF THE VARIOUS CAUSES

Information on the relative importance of the various possible causes of sterility or lowered fertility is entirely inadequate for drawing definite conclusions. Many reports have appeared, but in few cases have all or most of the possible contributing factors been considered. This problem is one which by its nature demands a careful, systematic approach if data are to have real value. For example, 50 cows that were sterile or had very poor breeding records might be examined and a certain type of infection found in a large proportion. Unless the infection is of a type that actually blocks the passages of the reproductive tract or inhibits the production of germ cells, it cannot be positively concluded that this is the true cause of poor breeding results. If, however, 50 other cows with good breeding records, kept under comparable conditions, were examined simultaneously and this type of infection was not found or was present in a much smaller proportion of the cases, then there would be better ground for suspecting that the infection was a contributing factor to the breeding difficulties. Similar precautions must be observed in obtaining and interpreting data, whether the factor being investigated is pathological, nutritional, physiological, or of some other nature.

A number of articles have appeared to which the reader is referred for an introduction to the literature on this subject. These include reviews by Orr and Darling (*880*) on physiological, genetic, and nutritional factors and by the Imperial Bureau of Animal Nutrition (*569a*) on nutritional factors, and a series of papers by Hammond (*466*), Parkes (*894*), Korenchevsky (*645*), and Edwards (*310*) on genetic, endocrine, vitamin, and disease factors in relation to sterility in domesticated animals.

Edwards points out that there is much ground for holding the view that the chief cause of sterility in our larger animals is some form of infection, and he gives a careful review of literature on this phase of the problem. This should not be interpreted to mean that elimination of infection will eliminate most of the cases of sterility or lowered fertility, but it does indicate that in approaching the problem of improving breeding results infections must be eliminated first. Any experimental studies of the effects of nutritional, endocrine, or other factors would certainly be unsound if infections were not eliminated or at least carefully controlled.

Polovtseva et al. (*930*) studied 100 ewes having a record of 2 to 3 years' sterility. In 85 percent of the cases pathological conditions were found in the reproductive organs. These were distributed as follows in the 100 ewes: Ovaries, 16 percent; uterus, 15; Fallopian tubes, 9; vagina, 25; and cervix, 78 percent.

Richter (*962*) found that in Germany and Hungary following the World War sterility in goats increased from a normal of 5 to 20 to 25 percent, and in sheep from 10 to 40 percent. These increases in sterility were attributed to inadequate feed, but it is possible that there were other contributing factors.

Andrews and McKenzie (*24*) studied 79 mares of which 26 were showing deviations from the normal picture at the particular estrual period during which they were being bred. Of these 26 mares, 9 exhibited the condition of split estrus in which all signs of estrus proceeded in a normal manner except that the mares showed two periods of receptivity to the stallion instead of one continuous period, 4 ovulated 2 or more days after the end of estrus, and 7 ovulated without showing signs of receptivity to the stallion even though other signs of estrus were present.

McKenzie and Terrill (*733*) found that of 17 ewes operated upon at the first estrus of the season, 16 had corpora lutea that were approximately one estrus cycle old, indicating that ovulation occurred without estrus in these ewes.

Hammond (*465*) found that only 67.4 percent of the ova shed by 22 sows were represented by normal fetuses, the observations being made at various intervals during pregnancy, while Corner (*227*) found that 10 percent of the ova in swine do not divide after fertilization, approximately 10 percent develop part way (blastocyst stage) and then degenerate, and another 5 to 10 percent become abnormal during later periods of gestation, so that only about 70 percent of the ova are represented by living pigs. These are losses in sows that actually became pregnant and do not include infertile matings.

Reports by many workers have shown that failure to properly synchronize the time of breeding with the time of ovulation results in lowered fertility. The life of spermatozoa is short after ejaculation into the female tract and the ova must be fertilized within a short time after ovulation. Ovulation occurs near the end of estrus, hence the chances of fertilization are increased if breeding takes place at or after the middle of the estrus period.

The use of artificial insemination has increased rapidly in recent years and much research has been done to develop and improve techniques. This promises to be a very useful method in areas of intensive livestock production, particularly by allowing the increased use of outstanding proved sires. The hope has been expressed by some that it would cure many problems of low fertility. The proportion of fertile breedings resulting from artificial insemination with fresh semen is essentially the same as that obtained from natural insemination. The chief advantage of artificial insemination is that contact of the male with females is avoided, when collections are made with the artificial vagina, thus reducing the chances of spreading infections such as contagious abortion. This assumes, of course, that sterile instruments are used and that other necessary sanitary precautions are observed. When a well-trained man manages the operation and also checks the females carefully for pregnancy the breeding record should be improved, because infertile animals should be discovered earlier than is the case otherwise and proper attention may be given to them. This close attention may also make possible closer observation of the females so they may be bred at the optimum time in the heat period. Close observation of the male is also necessary under these conditions and any lowering of fertility in the male should be detected earlier than would otherwise be the case.

While artificial insemination gives promise of being useful in these and other ways, it must be remembered that it is a technique which should be used only by persons familiar with the anatomy and physiology of the reproductive organs and with the fundamentals of sanitation, and who are equipped with adequate instruments and trained in their use.

Phillips and McKenzie (*922*) and McKenzie and Berliner (*731*) report cases in which low fertility and temporary sterility in rams was associated with high temperatures during the summer months.

Work of the type discussed is indicative of what may be accomsuccessful flushing two conditions must be fulfilled: (1) The flushing must result in a significant gain in weight over the unflushed ewes (*212*, *262*, *750*); (2) the nutritional plane of the ewes before flushing must be below the level that permits the highest possible lamb crop for that particular breed. If the ewes are on a very high nutritional plane to start with, flushing may lead to a significant gain in weight without an increase in the lamb crop (*212*, *262*). However, it is important to emphasize that there is no evidence of decreased fertility as the result of flushing a flock already in a very high state of nutrition. In fact, two reports indicate that no decrease occurs under such conditions (*212*, *262*).

If the results of flushing are accepted without further question, it may still be objected that these results follow a high plane of nutrition maintained for a short time. In the rat colony at Yale University, the animals have been inbred for many years without addition to the original stock. The manner of handling the animals has not changed. But since 1932 the stock diet has been changed by increasing the vitamin content and the protein content to allow a greater rate of growth. With the new diet, the average daily gain has increased about 100 percent. The size of the mature animals has increased enormously. The largest rats in this colony fully equal the largest rats yet produced by injections of the pituitary growth hormone. Yet with this increased growth rate and increased size on the higher plane of nutrition, the percentage of fertile matings has increased from about 70 percent to over 90 (*23*, *38*, *173*).

To be sure, this experiment has not been precisely duplicated with other species of animals. But a flock of purebred range ewes with a lambing record of 80 to 100 percent produced lamb crops that averaged 135 percent for 6 years after being transferred from the range to an experimental farm (*498*), and reached a high of about 160 percent for the 3 years in which they were in their prime. During this 6-year period the plane of nutrition was continuously higher than that on the range. It might be argued that a still higher plane of nutrition would have led to a decrease in the lamb crop, but there is no satisfactory evidence that a high plane of nutrition, or fatness by itself, leads to sterility in any species.

Granting for the moment that fat animals may be found to have a lower fertility as a group than leaner animals, this does not necessarily mean that fatness is the cause of the sterility. It might just as well be the other way around—that the sterility is the cause of the fatness. The effects of castration on body weight and fat deposition in most species of animals are well known. Perhaps a more likely situation is that fatness and sterility occur together as the result of some cause common to both. In the human species, a condition of obesity and sterility results from a lesion in the brain base that also involves the pituitary gland. This can be duplicated in the experimental animal (*1083*). This example is cited not with the intention of explaining the often cited relation between fatness and sterility on any particular basis, but merely to show one condition in which fatness is not the cause of sterility.

Careful experimental work is needed to determine whether it is possible to lower the fertility of a group of healthy animals by subjecting them to a continued high plane of nutrition, and to raise the fertility of the same group by returning them to a lower level of feeding. Until this is done, perhaps a fresh point of view would be helpful—a point of view willing to accept sterility as the cause of fatness just as easily as to accept fatness as the cause of sterility.

VITAMINS AND REPRODUCTION

There is no evidence to indicate any special requirement of vitamin D for reproduction, and this is true also of vitamin C. Diets producing definite symptoms of scurvy in the guinea pig do not interfere with estrus or ovulation (*421*, *761*). Male guinea pigs dying of scurvy have normal testicles with normal sperm. A deficiency of vitamin B (old terminology) in the rat does interrupt the estrus cycle and stop ovulation in the female (*344*). However, such a deficiency also causes a severe decrease in energy intake. Restriction of energy intake to an equal degree on a complete diet results in equally severe disturbances in the sex organs (*748*). Consequently, it is difficult to say that the vitamin B complex affects reproduction beyond its effect on food intake. It is also noteworthy that male rats dying from vitamin B deficiency may show normal testes (*340*). In view of the difficulty of producing vitamin B deficiency in the larger domestic animals and the abundance of this vitamin in the common stock feeds, there is probably little need to be concerned about vitamin B deficiency in the breeding of farm animals.

Two vitamins, A and E, do influence reproduction markedly. In the rat, diets low in these vitamins may be sufficient to maintain animals in apparently good health and to permit growth at a rate not very far below normal, but not sufficient for normal reproduction (*5*, *344*, *346*). The reproductive system is therefore somewhat more sensitive to lack of vitamins A and E than the rest of the body, and apparent good health is not a safe guide.

In the rat a mild deficiency of vitamin A leads to an abnormal formation of horny scales on all of the soft membranes of the body (*5*, *344*, *760*). Not all parts of the body are equally susceptible to this change. Among the first to be affected in the female rat is the soft membrane of the vagina. At this level of deficiency there is no loss in weight. In fact the animal may continue to gain at a satisfactory rate, but there are definite abnormalities in reproduction. The estrus cycle, as determined by mating behavior, and ovulation are not at all affected (*5*, *341*, *343*, *344*, *346*, *759*, *760*), nor is the early development of the growing young in the uterus. The difficulty appears after the middle of pregnancy (*762*), when degeneration of the placenta takes place, resulting in hemorrhage and abortion. Many of the pregnancies that are not interrupted at this stage continue beyond the normal term. In such cases labor is abnormally long, and many of the young are stillborn. Mortality of the mothers is high during such prolonged labor.

Male rats are somewhat more resistant to vitamin A deficiency than female. While the female is showing early evidence of a lack of vitamin A, males show no damage to the testicle. With more severe deficiencies, when lesions begin to appear in the membranes of the eyes, the testes begin to show some damage (*761*). Even at this stage, however, the lesions are not very severe, and motile sperm is still being formed. More pronounced lesions are found only after the animal has lost some weight. Strikingly, this damage to the testicle can be repaired by doses of the vitamin too small to permit a gain in weight. The condition in the female rat also can be relieved by proper treatment with the vitamin even after a long period of deficiency.

The symptoms of vitamin A deficiency in the rat are almost identical with those seen in the cow and the sheep. In these species also the difficulty does not appear in the estrus cycle or ovulation, but late in pregnancy, leading to abortion or premature labor with the birth of weak or dead young (*496*, *498*, *776*). In these larger animals also, the abnormalities of pregnancy may occur on diets that do not produce pronounced impairment of the general health of the mature animal. From the evidence in the rat, the cow, and the sheep, therefore, it would seem clear that the vitamin A requirements for successful reproduction are somewhat higher than the minimum requirements for maintenance of the mature animal. It is not at all clear, however, that the requirements for reproduction are any higher than those for normal growth.[4]

In the female rat, vitamin E deficiency resembles vitamin A deficiency to the extent that here again the trouble does not involve the estrus cycle or the ovary (*346*). It occurs after the middle of pregnancy and leads to the resorption of the growing young in the uterus. The disease differs from that produced by vitamin A deficiency in that the membranes are not attacked and abortion does not occur (*348*, *762*). The disease may be regarded as one that interferes with the growth of the young before birth. In the male, the disease attacks the germ cells which produce the sperm, and the condition cannot be cured by the administration of vitamin E, so that permanent sterility may result. This is in sharp contrast to the effects of a lack of vitamin A.

So far, vitamin E deficiency has been studied chiefly in the rat because it has been impossible to produce pathological symptoms from it in other animals. On a diet that produces complete sterility in rats, goats and rabbits continue to breed for two or more generations without difficulty (*766*, *1239*). Regarding vitamin E deficiency purely as a laboratory product is probably justified. Although definite cases of a natural deficiency of other vitamins are recorded for man and animals, there is on record no known instance of a vitamin E deficiency occurring in nature. This is undoubtedly a reflection of the widespread distribution of this vitamin in all natural foodstuffs. Nevertheless one continues to hear of miracles performed by vitamin E concentrates, especially in curing habitual abortion in women and sterility in cows (*69*, *1059*, *1171*, *1172*, *1173*).

It will be recalled that true vitamin E deficiency in the rat does not produce abortion, nor does it interfere with estrus or ovulation. The publications on the effects of wheat-germ oil (vitamin E concentrate) on bovine sterility have not been concerned with any abnormality of pregnancy that could conceivably be attributed to a vitamin E deficiency. They have dealt with cows that failed to become pregnant following service at normal heat periods. It is difficult to understand how a single injection of wheat-germ oil at the time of service would facilitate pregnancy in such cows unless the injection somehow or other stimulated ovulation or prolonged the life of the egg. To be sure, there are reports that vitamin E injections in the rat induce estrus (*1117*) and also stimulate the ovary (*1166*). It has also been claimed that pituitary hormones are suitable substitutes for vitamin E in deficient animals (*1166*). Finally, the statement has been made (*990*) that the pituitaries of vitamin E-deficient rats are lower than normal in hormone content, though this claim has been disputed by competent investigators (*276, 843*). The claims for estrus-inducing or ovary-stimulating activity of vitamin E have been thoroughly discredited (*276, 869, 1009*). Perhaps it is permissible to characterize most of the vitamin E miracles as products of enthusiasm rather than of prudence. At least one group of American workers has not been able to confirm the reported beneficial effects of vitamin E concentrate in the breeding of cattle (*593*).

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[4] See the article on The Vitamins in Milk and in Milk Production, pp. 668.

THE RELATION OF MINERALS TO REPRODUCTION

The minerals that have been most prominently mentioned in connection with reproduction are phosphorus, calcium, and manganese. It is easy to find in the literature reports that a deficiency of one or another of these elements will interfere with reproduction. However, a critical analysis of the available data does not bear out these claims.

Perhaps the experiments most often cited are those dealing with phosphorus deficiency in range cattle. It is true that cattle on phosphorus-deficient ranges experience difficulties in breeding, but this is not necessarily due to a lack of phosphorus. In the first place, the low phosphorus content of the pasture is paralleled by a very low protein content, and there may in addition be still other deficiencies not yet recognized (*288, 494, 1129*). Again, pasture low in phosphorus is not very palatable, so that the food intake is far below normal (*494, 1129*). As a result the animals are obviously in poor condition (*1129*), and the multiple deficiency is complicated by partial starvation.

It has been reported that the addition of bonemeal to the diet of cattle on such ranges results in marked improvement in general condition and in breeding performance (*1129, 1131*) following the increased food consumption upon administration of the supplement. But in recent experiments on cows an uncomplicated phosphorus deficiency did not interfere with estrus or ovulation, despite the fact that the phosphorus deficiency was severe enough to lower the blood phosphorus to levels below those usually seen in range cattle on low-phosphorus ranges (*299*). Unfortunately the data are not yet extensive enough to warrant the statement that phosphorus deficiency is likewise without effect upon the number of live calves born. It is possible to state, however, that if phosphorus deficiency, uncomplicated by protein and other deficiencies, has any effect whatever on reproduction, it is not great enough to be indicated clearly in the experimental data so far obtained from cows.

The situation is similar in the rat. The low-phosphorus ration is not so palatable as one with a higher phosphorus content, so that food consumption is below normal by 25 percent or more (*443*). Nevertheless, when mature rats are placed on such a diet there is no interference with the estrus rhythm. When somewhat less mature rats are used, the low-phosphorus diet results in a marked diminution in rate of growth and a cessation of the estrus cycle. After an interval, however, the slowly growing rats eventually reach a mature size and the estrus cycle once more makes its appearance, despite the continuance of the phosphorus-deficient ration (*443*).

The mineral most closely associated with phosphorus is calcium, and claims have been advanced concerning the necessity of this element for normal reproduction. In the rat there appears to be no reason for such a claim, although there is some evidence that the addition of calcium to some diets results in better growth and more economical gains in weight (*1049*). In the cow, a calcium deficiency sufficient to lower blood calcium had no apparent effect on reproduction (*892*). Only in swine have any real effects of calcium deficiency been reported (*803*). Even here, however, the results of the deficiency are much more noticeable on the general health of the animal than on reproduction. With a disease severe enough to produce rough scaly skin, bending of the bones, and periods of temporary paralysis, estrus occurred normally for two or three generations (*263*, *349*). The number of young per litter and the average weight of the young at birth were undiminished, although one observer reports an increased percentage of stillbirths (*263*). There is general agreement, however, that lactation is seriously impaired by the low-calcium diet.

There is a widespread belief that manganese deficiency in the rat interferes with estrus and ovulation despite the fact that one of the most comprehensive studies on this question indicates the contrary (*875*). The early experiments in which the manganese deficiency was produced by milk diets fortified by iron and copper are responsible for this erroneous impression. Later work has demonstrated that the limiting factor on the milk diet was not manganese but energy, since the difficulty with estrus and ovulation was remedied by the addition of sugar to the diet (*1064*). Still unexplained, however, is the sterility in the male rat produced by diets low in manganese. The early experiments on this phase of the subject have not yet been repeated so that it is impossible to decide whether the sterility was due to an uncomplicated manganese deficiency or to some other factors not yet appreciated. No data are available on manganese deficiency in other species.

CARBOHYDRATE, FAT, AND PROTEIN

There is no evidence that carbohydrates have any influence upon reproduction (*344*). Completely fat-free diets do finally stop estrus and ovulation in the rat in about half of the females and decrease fertility in the males. This occurs, however, only when the experimental ration has produced severe kidney disturbances and skin lesions in badly undernourished animals. A small amount of fat in the diet will restore reproductive functions long before the animal has made any significant recovery in general health (*173*, *174*).

With protein the situation is a little different. Not only must the protein in the diet be quantitatively sufficient, but in addition it must be of satisfactory quality. A diet in which wheat is the only source of protein is inadequate for reproduction in the rat (*344*). When the dietary protein is gliadin (derived from wheat), estrus and ovulation fail even though the protein is fed at the level of 18 percent (*231, 901*). The amino acid lysine appears to be a limiting factor in this situation inasmuch as the addition of small amounts of lysine to the diet readily correct the abnormalities. When a better protein is fed, abnormalities of estrus and ovulation are encountered only at much lower levels. For example, casein must be reduced to 4 or 5 percent before the estrus cycle is interrupted (*442, 903*). With such a level of casein, however, the estrus cycle may stop in 4 to 5 days, and as long as the animals are held on this diet neither estrus nor ovulation occurs despite the fact that body weight and general health are well maintained. On such a diet growth does occur, but it is very much below the normal rate. On the low casein diets neither lysine (*903*) nor cystine (*900*) is a limiting factor. It is therefore not possible to state that lysine or any other single amino acid is exclusively concerned with the maintenance of ovarian function. There is one report that the administration of pituitary material will cure the ovulation failure resulting from protein deficiency (*231*). This is highly interesting but cannot yet be accepted as proof that low-protein diets produce their effects by diminishing pituitary function. Aspirin sometimes relieves headaches, but no one would contend that headaches are due to a lack of aspirin in the body.

In the rabbit very severe protein restriction (2-percent-protein diets and protein-free diets) for relatively long periods have very little effect upon estrus and ovulation despite the fact that the animals lose about 25 percent of their initial body weight. Moreover, no evidence could be obtained that such protein restriction interfered in any way with pituitary function.[5] In the larger domestic animals there are some experiments on protein deficiency, but the information at present does not permit a completely satisfactory comparison with the rat or rabbit. In general, it would appear that the larger domestic animals are not quite so sensitive to low-protein diets as is the rat (*263, 498*).

The question has often arisen as to the optimum level of protein in the diet. Even with the rat the impression has been that about 14 percent by weight is the optimum level for protein. Yet the magnificent results in growth and reproduction in the Yale rat colony have been obtained on a diet containing about 30 percent of protein (*22, 783*). When rats are allowed complete freedom in selecting their own diets from a choice of pure foodstuffs, they choose a diet containing about 30 percent of protein (*959*). So does the rabbit, and on this higher level of protein the rabbit gains weight faster and more economically than upon the kind of ration most breeders feed their stock (*125*). Cows, too, choose a diet containing much more protein than is usually fed (*849*).

It is strenuously objected that such diets contain more than the "requirements," and that therefore the cow is in error. Judgment in favor of the requirements as set up by man is perhaps unduly biased. Certainly the rat has an uncanny ability to choose precisely what it needs at any given time. If the adrenal glands are removed and the salt requirements go up, the rat voluntarily chooses the correct amount of salt to maintain its life. When the parathyroids are removed, the rat voluntarily increases the calcium intake without increasing the intake of other salts (*958, 960*). On diets deficient in vitamins of the B complex, the rat decreases the intake of both protein and carbohydrate and increases the intake of fat (*961*). To enable the rat to make these amazingly intelligent adjustments, however, it is necessary to give the animal a wide enough selection so that the diet can be balanced readily to fit the needs. Perhaps some of the difficulty in self-selection experiments on the larger animals is that the choice has been limited to a few concentrates and supplements which may not represent the best possible combinations for the particular situation confronting the animal. The fact that pigs will not balance their rations with respect to protein if allowed a choice of cereal concentrates and linseed meal (*507, pp. 615–616; 820*) may be a reflection upon the amino acid and calcium deficiencies of linseed meal rather than upon the pig's judgment. If the pig is allowed a somewhat wider choice—for example, meat scrap in addition to the cereal and linseed meal—the animal will do very well indeed (*820*). What is really best for the animal may not always coincide with what is best for the farmer's pocketbook, but it would be very interesting to repeat some of the self-feeding experiments on larger animals with a technique similar to that used on the rat.

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[5] FRIEDMAN, M. H., and FRIEDMAN, GERTRUDE S. Unpublished experimental data.

DIETARY INGREDIENTS NOT YET IDENTIFIED

Unfortunately it is not at all certain that present knowledge encompasses all of the dietary ingredients necessary for successful reproduction, especially in herbivorous animals. It is probably significant that synthetic rations that are completely satisfactory for the rat are altogether unsatisfactory for the rabbit, goat, or sheep, even for maintenance (*528, 741*). There may be some very important ingredients in roughage or in pasture that have not yet been identified. Cows maintained on dry rations do not seem to reproduce as well as those allowed some access to pasture (*776*), and shy breeding, which develops in the barn on winter rations, seems to be alleviated by pasture. These impressions cannot be accepted as proof of the presence of some unidentified essential ingredients in pasture grass, but neither can they be ignored, especially in view of the finding of ovary-stimulating substances (*397, 398, 399*) in young grasses, as noted elsewhere in this Yearbook.[6]

NO SPECIFIC DIETARY REQUIREMENTS FOR REPRODUCTION

Throughout the entire literature on the relation of nutrition to reproduction the factor of underfeeding has not received sufficient attention. Even with a completely balanced ration, decreased food intake is capable of stopping the estrus cycle and ovulation in the female and sperm formation in the male. Owing to the decreased palatability of diets severely deficient in one or more elements, this factor of underfeeding has complicated much of the experimental work, so that breeding difficulties that have been attributed to specific dietary deficiencies may very well have been merely the result of partial starvation.

With notably few exceptions, the dietary requirements for reproduction, qualitatively and quantitatively, do not exceed the requirements for maintaining mature animals in good health. Vitamin E is one exception to this statement, but this vitamin is so widely distributed in nature that, for the present at least, vitamin E deficiency may be regarded as a laboratory curiosity.

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[6] See Glands, Hormones, and Blood Constituents—Their Relation to Milk Secretion, p. 685.

Not in the same class are the exceptions which must be made with respect to protein and vitamin A. It is quite possible that protein deficiencies not readily detectable by any signs in the mature animal can produce lowered breeding performance. In the case of vitamin A, there is a problem of practical importance, for with moderate restriction of vitamin A intake mature animals may suffer abnormalities of pregnancy without showing any obvious signs of ill health. Moreover, the degree of vitamin A deficiency required to produce these abnormalities can probably be reached in ordinary farm practice when the stock is fed low-grade hays for a period of several months.

Yet even in the case of protein and vitamin A, the requirements for successful reproduction have not been shown to be beyond those for normal growth. Hence, if breeding difficulties are encountered in any stock in which the immature animals show normal growth and the mature animals show general good health, it would probably be profitable to search for some infection or sexual pathology before giving serious consideration to possible dietary defects.

THE RELATION OF NUTRITION TO THE PRODUCTION OF HIDES AND WOOL

by John I. Hardy and Imogene P. Earle[1]

THERE is no doubt that nutrition affects hides and wool, but research has been too limited to give any detailed results. In summarizing the existing information, this article shows definitely that the level of feeding of sheep greatly influences both the quantity and the quality of the wool produced.

THE MANY USES of animal skins and their associated fibers—wool, hair, and fur—make the production and quality of these materials important in the economics of essential commodities. However, except in those few enterprises specifically devoted to the production of furs, animal skins are more often than otherwise only byproducts of other industries, and the production of animal fibers, even in the sheep industry, is frequently secondary to the production of meat. Relatively few studies have been devoted primarily to the factors influencing production and quality of skin compared with the large amount of research on the production of animals for meat. More attention has been given to the production of animal fibers, especially as represented by the wool of sheep, and considerable progress has been made in this field.

Breeding, nutrition, climate, sex, age, and management of the animals all probably influence the growth of skin and its associated fibers—wool, hair, and fur. Fraser (*389*)[2] has pointed out in a review of the influence of nutrition on wool that "the maximum quantity and optimum quality of wool grown by sheep is determined by its genetic constitution," and that "the importance of nutrition lies in the provision of concrete materials for the full expression of genetic potentialities." This generalization probably applies to the production of other animal fibers and of skins as well. So far as is known, nutritive factors affecting the production of hide and hair are either dietary deficiencies or the factors that correct dietary deficiencies. It is believed that the amount and quality of body covering of an animal cannot be increased through change in the diet beyond the level resulting from a diet that supplies in adequate amounts all the dietary essentials for maintenance, growth, and reproduction. An improvement in quality beyond that attained on an optimum ration for health must be the result of changes in genetic factors or possibly in external environment. On the other hand, the kind and quantity of hide and hair produced modify the nutritive requirements of the animal.

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[2] Italic numbers in parentheses refer to Literature Cited, p. 1075.

STRUCTURE OF SKIN AND WOOL

A brief consideration of the nature and structure of skin and wool may lead to a better understanding of the role of nutrition in their production.

Skins of all mammals are anatomically and physiologically similar. Leather may be made from them all, although there is a wide range in the texture of the product obtained. Skins in their raw state consist of three layers, the epidermis or thin outside layer, a second thicker layer known as the corium, and a third layer of adipose tissue or flesh. In the process of tanning, the first and third layers are removed.

The epidermis is made up of cells—an underlayer of living epithelial cells and an outer layer of dead cells. This outer layer consists mostly of an insoluble protein, keratin, and affords surface protection to the body. As these outer cells are lost they are replaced by the under layer of living cells. The epidermis has no blood vessels of its own and must obtain its nourishment from the blood and lymph supplied by the blood vessels of the corium.

The corium is made up of interlacing connective-tissue bundles, elastic fibers, and smooth muscle fibers. The texture of the corium nearest to the epidermis is finer and the connective-tissue bundles are more closely interwoven, while the deeper portion nearest to the adipose tissue is more coarsely meshed. The fine-textured portion is recognized as the papillary layer and the coarser textured part as the reticular layer. It is the upper papillary portion that makes the grain in leather.

Wool, hair, and other animal fibers grow from cavities (follicles) that surround them. The wool fibers are first visible to the naked eye as they push up from the follicle through the minute recesses of the skin. The actual growth of a wool fiber takes place at the papilla in the bulb at its lowest extremity. The root ends of the fiber extend to varying depths in the skin. The cells formed at the papilla are pushed upward by the formation of new cells and become keratinized, or hardened, before they appear above the skin. Associated with the wool follicles are the sebaceous or fat-secreting glands, which provide oil to lubricate the fiber. There are also the sudoriferous glands, which exude sweat and suint. The excretions of these two kinds of glands form what is known as the yolk in a fleece of wool.

Pure wool substance is essentially a structure made of the protein keratin. This protein constitutes the major substance of hoof, nail, and hair and is present to a lesser extent in the cells of the upper layer of the epidermis. There are apparently many keratins differing somewhat in composition according to the structure in which they are found, the species and color of animal, and other factors, including the nutrition of the animal. All keratins are characterized by a high content of the sulfur-containing amino acid, cystine. Keratins differ from other proteins chiefly in their insolubility in neutral solvents and in their high sulfur content.

Hides also consist chiefly of protein; because of the complexity of their structure they are made up of a number of different proteins.

FACTORS INFLUENCING HIDE QUALITY

According to Tänzer (*1121*) both thickness and quality of hides—and consequently of leather—are influenced by sex, age, breed, management, and environment of the animals producing the skins, and in the case of sheep, by the amount of wool grown on the hide. Further, there is considerable variation in the hide from one part of the animal to another. The larger animals grow thicker hides, and the skin on the main body of the hide is thicker than that found on the head, neck, and legs. The skin is also thicker on the back than on the belly. Tougher skin is found on and near the shank, owing to the sparseness of hair and the mechanical activity of this portion of the animal. Bulls have thick hides, but the leather is soft and is held to tear more readily than that made from cows and steers, which have smooth, strong, elastic skin. Rams have thicker and firmer skin than ewes and wethers. Leather from young animals is softer and lighter in weight than that from older ones. Generally speaking, heavily wooled sheep seem to have thick, spongy skins. The skin of Merinos, for example, is thicker than that of wild sheep. Both cold and highly variable warmer climates are believed to cause the production of thick skin. Mountain range cattle, for instance, have coarser skins than those of lower altitudes that are fed in barns.

That nutrition also affects the thickness and quality of hide has been demonstrated by the work of Clark, Stuart, and Frey (*213*), who made a comparative study of the hides of full-fed and underfed lambs. In this study nine lamb wethers on full feed received a daily ration of 1.20 pounds of grain, 0.60 pound of corn silage, and 1.01 pounds of clover hay, while their twin brothers received an "under feed" daily ration of 0.22 pound of grain, 0.59 pound of corn silage, and 0.56 pound of clover hay. The feeding test lasted for 112 days, during which the full-fed lambs nearly doubled their weight while the weight of the underfed lambs remained practically the same throughout the feeding period. The final average body weight of the full-fed lambs was 88.7 pounds and that of the underfed lambs 49.9 pounds, and the weight of the whole skins was 7.888 and 3.72 pounds respectively. Grain, reticular layer, and whole skins all averaged thicker for the full-fed group (fig. 1). The finished leather in the full-fed group averaged 0.046 inch and that in the underfed group 0.026 inch in thickness. The leather of the full-fed group averaged much stronger and had a greater tear resistance and a greater stretch at the point of rupture, but the strength of cross sections of equal area was approximately the same. The grain surface of the leather from the full-fed lambs was more developed than that of the underfed group, which was appreciably flatter. The most significant chemical difference in the skins was that those of the full-fed group contained a higher percentage of fat and also more cystine.

Frey, Clarke, and Stuart (*394*) investigated the cause of fatty spots

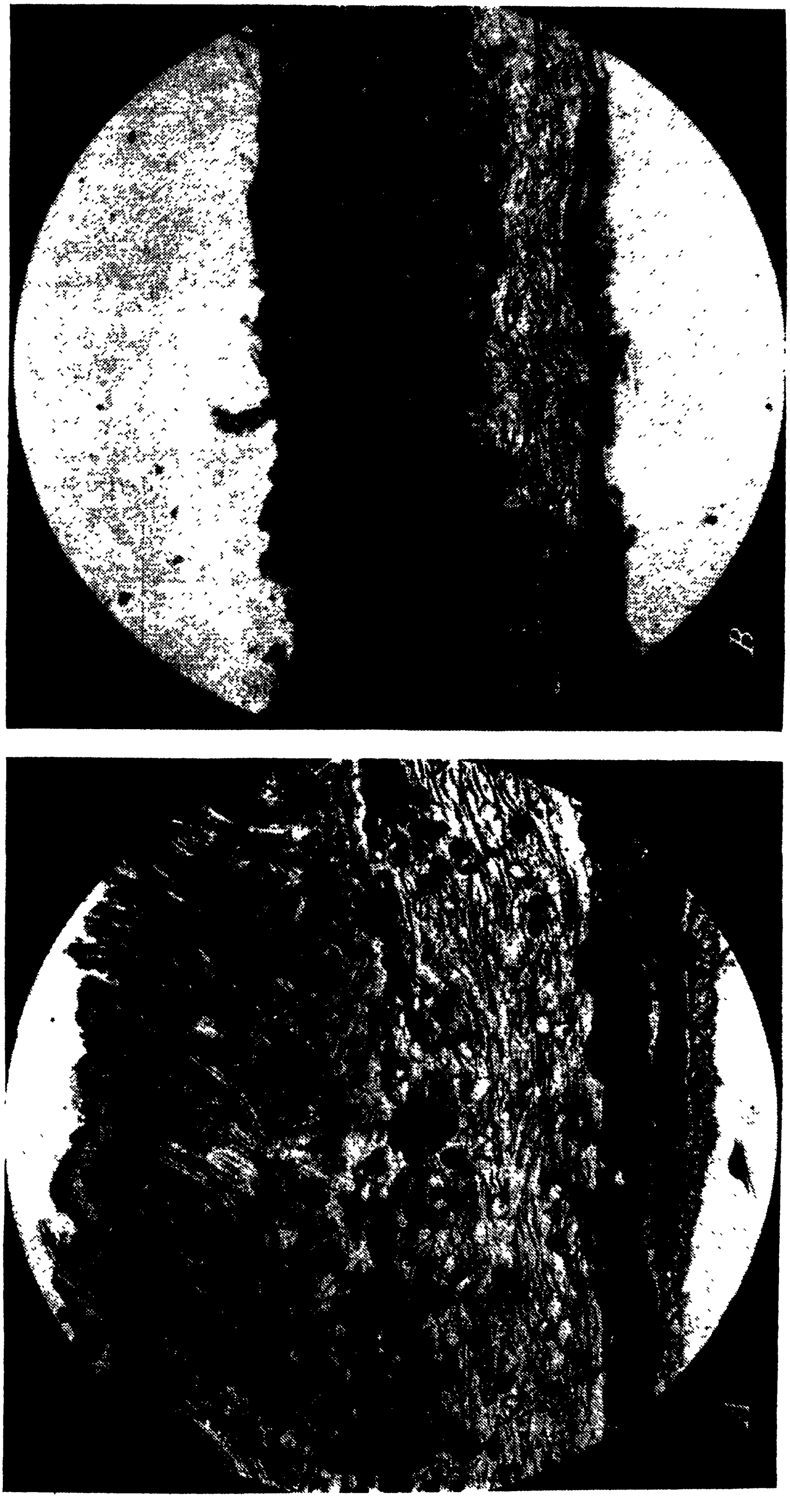

Figure 1.—Cross sections of skins of lambs showing differences in development as a result of feeding: *A*, From full-fed lamb; *B*, from underfed lamb. ×35.

or "kidney grease" in heavy cattle hides and leather and found indications that this defect may be associated with the increased fat content of hides from animals that have been on full feed.

EFFECT OF PLANE OF NUTRITION ON WOOL

Nutritional research on animal fibers has been concerned almost wholly with the wool fibers produced by sheep. For over 100 years reported casual observations have indicated that gross weight and quality of wool can be influenced by nutrition factors occurring under natural feeding conditions. The production of a fine light fleece has been associated with light soils, strong harsh wool with limestone soil, and a characterless wool lacking in crimp with a heavy clay soil. Further, it has been said that the best quality of wool is grown in a country that produces short sweet grass, and that liberal feeding increases weight of fleece. Experimental evidence obtained from controlled feeding trials tends to support these popular beliefs.

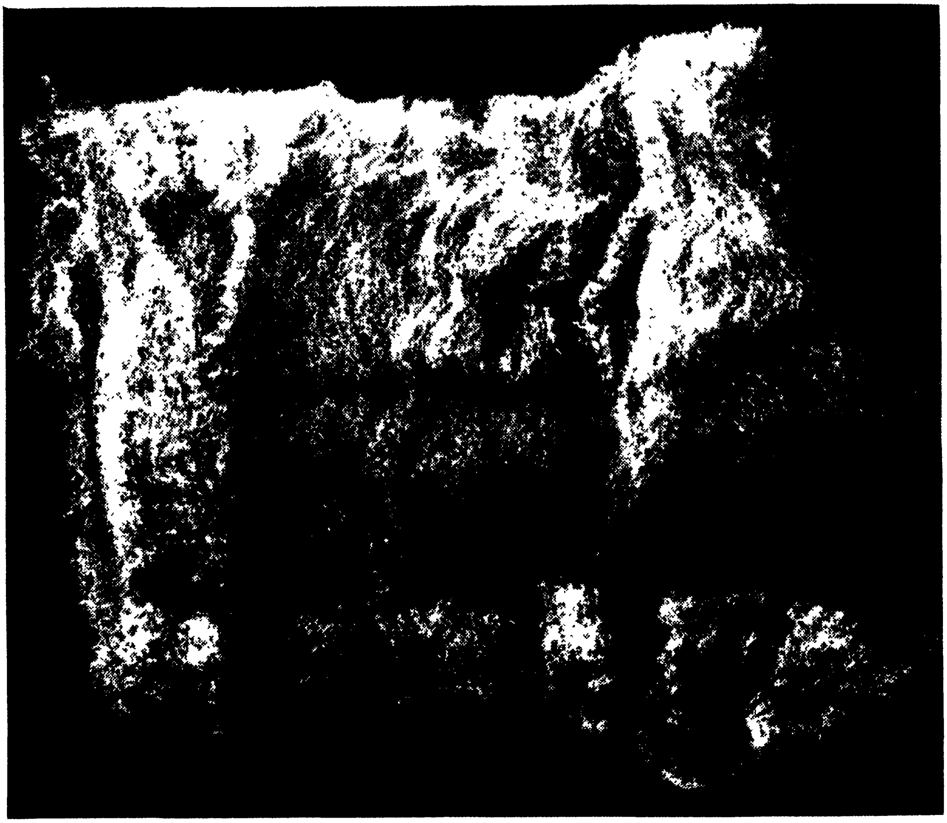

Figure 2.—A weak spot in a staple of wool caused by serious nutritional disturbance.

Tinley's observations (*1138*) indicated that lush pasture is associated with the production of a coarse, heavy fleece and sparse pasturage with a finer grade of wool. There is ample proof in the literature that any combination of feeds that maintains sheep in good vigorous condition tends to produce a heavier fleece than rations that are less satisfactory for maintaining general health and vigor. Wilson (*1235*) compared the fleeces of sheep on a fattening ration with those of sheep kept on a submaintenance ration. The sheep on the fattening ration produced 343 percent more scoured wool, and it was 141 percent longer and 207 percent higher in breaking strength than that produced by sheep on the submaintenance ration. Results reported by Snell (*1087*) are somewhat similar in that he observed that sheep on a low plane of nutrition produced lighter, shorter, finer, and more crimpy wool than their mates that were receiving more feed (fig. 2). Snell also showed that a lower plane of nutrition may result in shed fleeces.

It has been observed that when sheep have been improperly fed, even for a short time, and also in cases of disease, the fibers of the fleece often become reduced in diameter and as a result break easily (fig. 3). Such fleeces are said to be tender. When the condition of malnutrition or disease continues for a protracted period, the fleece becomes so weakened that it is easily plucked from the skin. This condition is thought to result from any cause that results in low vitality or poor health. In some of the Southern States considerable difficulty is encountered in maintaining sufficient control over parasites to keep the sheep healthy. In such localities shed fleeces are not uncommon.

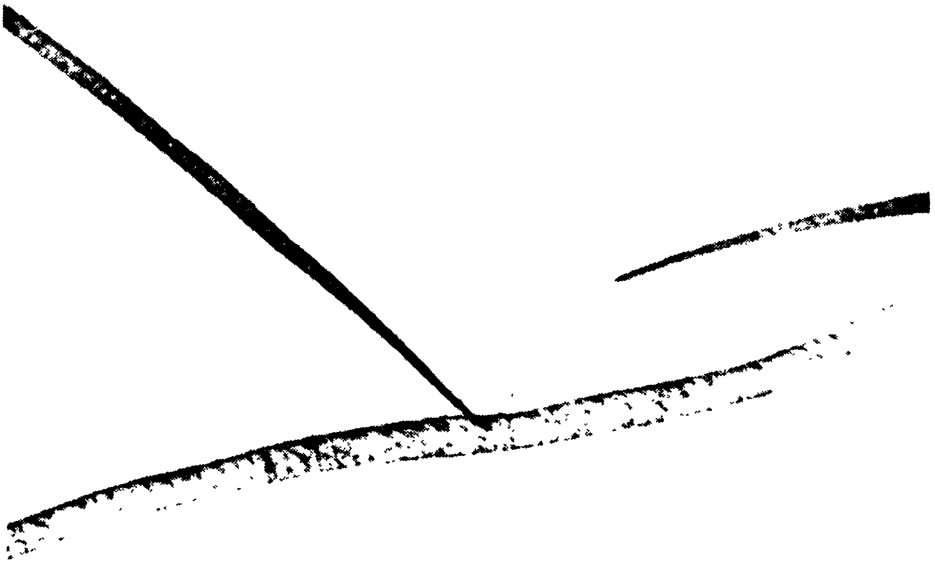

Figure 3.—A normal wool fiber contrasted with a weak broken one.

Authorities are not agreed, however, as to the extent or limitations of the effect of plane of nutrition on quality and growth of wool. It appears that the change in fleece weight resulting from a lowered plane of nutrition is in general associated with a decrease in length and diameter of fiber. The fact that improved nutrition of the sheep results in an increased coarseness of wool has occasionally been considered a disadvantage, but the slight lowering in count is more than offset by the increased value of the fleece as a whole.

ENERGY AND PROTEIN NEEDS FOR WOOL PRODUCTION

The energy and total protein stored in the production of wool have been estimated by Mitchell, Kammlade, and Hamilton (*801*) in the course of a study of the utilization of a ration of alfalfa hay and corn by lambs. They estimated that during the process of fattening, while body weight increased from 65 to 70 pounds to 90 pounds, the increase in amount of wool accounted for 8.8 percent of the dry matter gained, 26.3 of the protein, 2.1 of the fat, and 5.2 percent of the energy. The daily wool growth of these lambs contained 0.086 pound of protein and 377 calories for each 1,000 pounds of live weight. These same investigators in an earlier experiment with mature sheep found a more rapid daily wool growth equivalent to the deposition of 0.149 pound of protein and 566 calories per 1,000 pounds of live weight.

Since wool fiber is chiefly protein, the study of effect of nutrition on the production of wool is especially concerned with the metabolism of protein and the conditions modifying it. Considerable work has been done to determine the effect of feeding high and low levels of protein. Results of such trials have sometimes seemed contradictory, but in general they tend to support the conclusion that the total protein requirements of sheep are not remarkably high in spite of the extra protein required for wool production, and that protein in excess of the requirement for maintenance and growth is apparently without effect on wool production.

Marston (*753*) fed blood meal as a protein supplement to a large group of Merino ewes and lambs on the range and obtained a 35-percent increase in clean fleece weight as compared with the group of controls receiving no blood meal. He attributed this increase to the content of the amino acid, cystine, in the protein of the blood meal. However, Fraser (*389*) has pointed out that these results are also open to the interpretation that the level of protein, rather than content of cystine, may have been the controlling influence, since Marston did not feed the control group a like amount of protein poor in cystine. Fraser and Roberts (*391*) were unable to show that wide variations in the protein level when other nutritional factors were kept constant caused any significant difference in wool charactersitics. It is believed, however, that the basal ration in this study contained sufficient protein to provide for both body growth and wool growth.

CYSTINE REQUIREMENT

Much of the research on the relation of nutrition to wool production has been directed in recent years to the role played by sulfur or sulfur-containing compounds in the growth of wool. Sulfur occurs in protein as one or both of the two sulfur-containing amino acids, cystine and methionine, and as inorganic sulfate. In the protein of wool or hair, most of the sulfur present is accounted for by the cystine, which constitutes approximately 13 percent of the keratin, whereas the proteins in animal and vegetable foods contain only 0.3 to 4 percent of cystine.

For many years cystine has been considered indispensable for growth and health and incapable of being synthesized by the animal body from other substances. If it is assumed that cystine must be supplied preformed in the food, a low level of protein in the pasture or other feed or protein low in cystine would seriously limit wool growth. It has been suggested that the capacity of any territory for carrying sheep is determined by the content of cystine in its pasture grasses.

However, the requirements of sheep for preformed cystine have not been determined. Several workers have suggested that cystine is synthesized within the body of the sheep. Fraser and Roberts (*391*) estimated that the consumption of cystine was not sufficient to account for all that was laid down in the wool grown. They suggested that cystine was synthesized by the wool follicle. Rimington and Bekker (*967*) also calculated that the amount of cystine deposited in the wool of sheep during a year was more than was contained in all the pasture grass they could possibly have consumed. These workers suggested that cystine must be synthesized from proteins by bacteria in the rumen and intestine. Such conclusions, however, are based on available analyses of the cystine content of pasture herbage and other feeds and are open to question because of the unreliability of methods used in the determination of cystine in feeds containing carbohydrate.

Another line of investigation that may have an indirect bearing on the problem of the requirements of the sheep for preformed cystine deals with the relationship between cystine and methionine. Recently Rose (*986*) has shown, as a result of experiments with rats, that methionine rather than cystine is the indispensable factor. The inclusion of methionine in a cystine-free diet induced as rapid growth as the inclusion of both cystine and methionine. Cystine without methionine, however, was without effect, although cystine with a suboptimal quantity of methionine stimulated growth. Marston (*754*) studied the effect of administration of cystine, cysteine (a compound that yields cystine on oxidation), sulfur, and methionine on the growth of wool on a ewe receiving protein-poor rations. It had been found that on the basal ration alone ewes could maintain their weight and produce about 60 percent of the wool usually grown on pasture. Marston found that 1 gram of cystine added to the daily ration increased the growth of wool about 14 percent. Wool production was increased 34 percent when 1 gram of cysteine was injected daily, instead of being fed, to avoid destruction of the bacteria in the intestinal tract. The daily addition of 1 gram of sulfur to the ration was without effect. A small but not very significant increase in wool growth resulted from the daily injection of sufficient methionine to supply the same amount of sulfur as 0.5 gram of cysteine.

This work indicates that cystine (or its derivative cysteine) is more readily available for the keratinization of wool protein than methionine and lends support to the idea that the feed is the chief source of wool cystine.

EFFECT OF CARBOHYDRATE ON WOOL GROWTH

Fraser and Nichols (*390*) have studied the relation of the carbohydrate content of the diet to wool growth and have shown that though wool is a protein structure it can be influenced by the carbohydrate in the diet. They fed a group of sheep on a balanced maintenance ration, half the sheep receiving 1 pound of maize daily in addition to the basal ration. These animals had double the wool production of those not fed maize. The increase in weight of wool seemed to be chiefly due to the greater thickness of the individual wool fiber. This effect was probably due to the fact that the readily available carbohydrate in the maize could be used for energy and hence the available protein in the ration was utilized more efficiently for building and'repair.

OTHER NUTRITIONAL FACTORS

Little work has been done on the specific effect of the various nutritive factors other than proteins on the development of wool. Experiences in practical sheep raising have demonstrated, however, that well-fed animals have good fleeces and that many nutritional deficiencies interfere with the growth of wool.

The importance of a sufficient supply of minerals in the diet has been recognized, and mineral deficiencies have been the subject of much research. There is no evidence that mineral deficiencies interfere with the growth of wool except as they affect the general health of the animal. It has been observed that under circumstances that impose a phosphorus deficiency on sheep there is a decrease in wool production. The evidence indicates, however, that the decrease in feed consumption induced by the phosphorus deficiency, and not a specific lack of the mineral, is responsible for the interference with wool growth. Correction of phosphorus deficiency, therefore, serves to improve wool growth insofar as it increases the intake of protein, carbohydrate, and other nutritive elements.

The results of work with laboratory animals in connection with the study of vitamins has shown that dietary deficiency often causes a rough hide, a poorly developed coat, or even the loss of hair. A notable example is the dry, curly hair obtained by Hughes (*556*) on pigs kept on diets deficient in vitamins of the B complex.

With the knowledge that has been acquired from studies on small laboratory animals and on some kinds of livestock, a new field is indicated for research on animal fibers and hides that should yield fundamental information concerning their production. New techniques now being perfected for measuring quality in fibers and hides should greatly expedite such a program.

THE NUTRITION OF VERY YOUNG ANIMALS

by Imogene P. Earle [1]

VERY young farm animals have rather special nutritional needs that are normally supplied by the milk of the dam. Sometimes, however, the young animal is an orphan, and frequently young animals are taken away from their dams at an early age. This discussion deals with calves, foals, kids, lambs, pigs, and puppies, telling about their nutritive needs and covering such subjects as the characteristics of colostrum milk, substitutes for mother's milk, and the weaning process. Another article in this book covers the feeding of dairy calves in greater detail.

VERY young mammals have special nutritive requirements which, under natural conditions, are adequately met by the milk of the dam. This milk is a food adapted to the more or less undeveloped eating habits and digestive functions of the offspring and is designed by nature to meet the specific nutritive needs of the newborn of the species for which it is supplied. Thus for a period following birth, the young mammal remains more or less dependent on its dam for nourishment. This suckling period is one of changing requirements and of transition from the complete dependence of the fetal state to a condition of entire nutritional independence from the maternal animal.

Immediately after birth most young mammals are nourished entirely on milk. Other foods are gradually substituted for milk until they have replaced it entirely, and from then on the young animal may be fed the same varieties of feeds supplied to the adults.

Where the nutrition of the young is the sole consideration, the most satisfactory and economical procedure for feeding young mammals during the suckling period may be outlined as follows: (1) The proper feeding of the dam for the production of a sufficient supply of milk; (2) opportunity for the young to suckle their dams at will for a suitable period after birth; (3) at an advanced stage in the suckling period, the provision of suitable feeds to supplement the dam's milk.

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Under certain circumstances it may be necessary or desirable to feed some substitute for the natural milk of the dam, either from birth or beginning at some time after birth. In the case of the cow, where the economic value of the milk must be considered as well as the nutrition of the young, considerable attention has been given to studies of adequate methods of feeding the calves on a minimum amount of whole milk. Feeding of the young of all farm species becomes a problem when the dams die or refuse to suckle their young, or when their milk is insufficient in quantity or is unsuitable for some reason, such as disease. In such cases, particularly if the animals are of valuable stock, it becomes of practical importance to be able to feed the young animals by hand. The labor involved is no small item, however, and may be a limiting consideration. The careful preparation of feed, and the frequency with which the young must be fed during each 24 hours, all tend to make any system of hand feeding rather expensive aside from the actual cost of the feed consumed. The saving effected on feed consumed by dairy calves more than offsets the cost of labor.

The feeding of maternal animals for the production of milk is treated elsewhere. The present article is concerned primarily with a discussion of the general nutritive requirements of the very young; the functions and characteristics peculiar to the colostrum and milk of maternal animals of different species; and some substitutes that have been used to replace, either wholly or partially, the natural food of sucklings. The article will also include a brief treatment of feeds suitable for supplementing the dam's milk during the suckling period. The animals with which this discussion is chiefly concerned are young calves, foals, kids, lambs, pigs, and puppies.

INFLUENCE OF IMMATURITY ON NUTRITIONAL REQUIREMENTS

From the point of view of nutrition, the birth of a young mammal marks an abrupt and radical change from the state within the uterus—intra-uterine—in which it is passively nourished by the blood of the mother, to an environment in which the still immature organism must take in its own food, digest it, and absorb from it the factors required for maintenance and further development. The state of development of the newborn and the degree of dependence on the maternal animal vary in different species. For example, the young guinea pig at birth is quite active; it scampers about as soon as born, and will begin to eat whatever food is available to the mother almost at once. Young puppies on the other hand are entirely helpless; their eyes are not open until 9 to 14 days after birth, and it is not until some time later that they are able to walk about.

While the newborn of some species are more mature, with respect to their ability to obtain and assimilate food, than those of others, in no mammalian species is the young animal equipped at birth to maintain itself entirely on the kind of food suitable for the adult. In the first place it is deficient in the digestive enzymes operating in the adult. Further, its metabolic rate exceeds that of the adult, and consequently its energy requirements for maintenance alone are greater in proportion to size. In addition to energy requirements, its demands for building materials—proteins and minerals—are great, since the most rapid growth occurs in the suckling period. This means that the feed must be of a kind the young animal can easily digest, and that it must be fed frequently in order that it may have a sufficient quantity to meet its demands.

Another factor which must be considered in connection with a young animal's early nutrition is the undeveloped power for building up active resistance against bacterial infections. The mature animal actively resists many kinds of commonly occurring bacteria that invade its body by developing immunity-conferring substances that constitute a protection against diseases caused by these bacteria. The very young animal apparently has not the same ability as the mature animal for developing its own immunity to these diseases, and hence is largely dependent for protection on the antibodies that have been conveyed to it by the dam, either through the placenta before birth or through the colostrum, or first milk, shortly after birth.

In all mammals the developing embryo or fetus is nourished through the placental tissues, which constitute the attachment of the fetus to the uterus. The placenta accommodates both maternal and fetal circulations, holding them apart physically so that the maternal blood can never be directly introduced into the fetus, yet permitting the passage through the separating membranes of those substances that make up the food supply of the fetus. The structure of the membranes separating the two circulatory systems varies in different species.

It has been suggested (*949*)[2] that the permeability of these membranes to immune substances varies according to the number of layers of cells composing the separating membranes. In human beings and in the rodents the placenta interposes only one layer of cells between the maternal and fetal circulations, and immune substances are transferred, in part at least, through the placenta. The human infant at birth apparently has a supply of many, if not all, antibodies present in the circulating blood of the mother and hence is resistant to those diseases to which the mother is immune. In the pig, the horse, and the ruminants a multiplicity of cell layers intervenes between the maternal and fetal bloods, and in these species there is apparently no transfer of immune bodies through the placenta. The newborn of these species are dependent on the absorption of such substances from the colostrum of the dam. In the carnivores, exemplified by the dog, the separating membranes are made up of only two or three cell layers, and the possibility of placental transfer of immunity appears greater than in other species of domestic animals. Hence immunity may well be less of a nutritional problem in the puppy than it is in the colt and calf.

COLOSTRUM

Observations over the course of many years have shown that normally the products of mammary secretion of the maternal animal are satisfactory foods for her young. The requirements of the newborn differ from those of the older suckling in that they are those of a less mature animal. They are, however, adequately met by the colostrum, the first product of mammary activity after birth.

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[2] Italic numbers in parentheses refer to Literature Cited, p. 1075.

The colostrum differs substantially from the later milk. It is a much more concentrated fluid—that is, it has a higher percentage of solids. The constituents of the later milk are present but in different proportions. In addition, other factors are present which give colostrum certain biological properties that the later milk does not have. The composition of the colostrum varies within wide limits and changes rapidly following the birth of the young. There is considerable variation in the length of time during which the colostral characteristics of the milk persist, even in different individuals of the same species. Usually, however, these characteristics are not observed in the milk after the fourth or fifth day following birth.

The most significant difference in chemical composition lies in the high concentration of protein characteristic of colostrum from all species. This protein belongs largely to the group called globulins, and it has been found to be identical (*241*, *1206*) with the globulins in the blood serum of the same animal. The concentration of globulins has been reported to run as high as 17 percent in mare's colostrum and as high as 15 percent in ewe's and sow's colostrum (*289*). The percentage of globulin rapidly decreases in a few hours, as the data presented in table 1 show for the mare, goat, and ewe (*289*).

TABLE 1.—*Rapidity of change in concentration of certain proteins in colostrum of the mare, goat, and ewe*

Species of animal	Time after parturition	Proteins present in colostrum			Species of animal	Time after parturition	Proteins present in colostrum		
		Globulins	Albumin	Casein			Globulins	Albumin	Casein
	Hours	*Percent*	*Percent*	*Percent*		*Hours*	*Percent*	*Percent*	*Percent*
Mare	1	11.45	1.76	6.04	Ewe	0.5	14.28	1.79	6.51
	12	2.06	1.22	2.40		24	1.21	.99	4.72
	24	.42	.66	1.84					
Goat	1	8.18	.69	6.32					
	16	1.83	.39	3.43					
	24	.69	.49	3.19					

It has also been shown that the colostrum of the mare, cow, goat, and ewe may contain antibodies—bodies that protect the animal against foreign substances, such as bacteria and toxins—in higher concentration than does the blood and that these are associated with serum globulins of the same animals (*60*, *356*, *691*, *758*) The concentration of antibodies apparently diminishes as globulin concentration diminishes following parturition, although it is possible to have colostrum of relatively low globulin and high antibody concentration. It has been assumed that the colostrum globulins are probably serum globulins that have been secreted unchanged together with the associated antibodies from the blood of the animal.

Practical observations have shown that newborn mammals have a better chance of survival when they receive the first milk of their dams soon after birth. Hence several functions have been attributed to this first milk or colostrum. Many livestock owners still think the chief function of the first milk is that of a laxative essential for the removal of the meconium, the first matter discharged from the bowels of the newborn. Bauer (*67*) and Birk (*105*) have expressed the view that colostrum, with its high concentration of blood proteins, is especially designed as a suitable and necessary food for the young animal in the first and most difficult stage of adjustment after leaving the uterus, where he has been nourished wholly by the maternal blood. The high concentration of nutrients in an easily digested and assimilated form is doubtless one of the advantages of colostrum to the young.

The possible function of colostrum in supplying the newborn animal with vitamins should not be overlooked. Dann (*260*) found that cow's colostrum has a concentration of vitamin A which may be 70 times as great as that in later milk. This is especially significant in view of the fact that the body of the newborn calf has a very low supply of vitamin A (*444*). Cow's colostrum may contain also 3 times as great a concentration of riboflavin (vitamin G) as the later milk (*647*). This concentration of vitamins in the colostrum may not occur in all species.

The most important function of colostrum, however, is undoubtedly its role in the passive immunization of the young against disease. The young calf, foal, kid, lamb, and pig (*356, 691, 758, 842*) lack at birth the antibodies present in the blood of the dam and the protein fractions (globulins) with which these antibodies are closely associated in the blood serums (*289*). Shortly after the ingestion of colostrum, both antibodies and globulins appear in the blood serum of the young suckling. These substances absorbed from the colostrum usually endow the newborn with sufficient resistance to protect it from infection by many of the kinds of bacteria commonly present in the usual farm environment until it is able to elaborate an active immunity. Without the passive immunity conferred by the colostrum, a large percentage of the young succumb to infection by organisms that do not affect older animals.

SERUM AS A SUBSTITUTE FOR COLOSTRUM

The remarkable ability of the gastrointestinal tract of the newborn to absorb immune bodies and globulins from the colostrum diminishes rapidly after birth. After the second day following birth, absorption can no longer be readily demonstrated. This permeability is somewhat selective, since it permits the passage of large amounts of colostrum globulins, while apparently no demonstrable amounts of casein and lactalbumin are absorbed.

That antibodies can also be absorbed from serum either of the same species or of another species when these products are fed by mouth or are injected under the skin has been demonstrated in foals, lambs, puppies, and calves (*758*). Since serum from the dam contains the same immune bodies found in the colostrum and is an easily absorbed substance, serum from the same species is the most obvious substitute for colostrum in the transfer of passive immunity. In fact, it has been fed as a substitute for colostrum to calves (*1085*) and to foals and lambs (*406*).

Smith and Little found 200 to 350 cubic centimeters of cow serum fed in milk to young calves to be partially successful as a substitute for colostrum. Better results were obtained when 60 cubic centimeters of serum was injected and 120 cubic centimeters fed. In some experiments reported by the Bureau of Animal Industry 1 liter or more of horse serum substituted for a like volume of water in a dried-milk mixture was used with entire success to replace colostrum in rearing healthy foals (*406*). Other colts in the same experiment, fed the milk mixture without the serum, all died. This represents an extreme rather than an average death rate, since it is not impossible that some colts may survive without the benefits of colostrum or serum. Sheep serum to which was added 15 percent of dried whole milk was used as a substitute for ewe's colostrum, but with somewhat less striking results.

COMPOSITION AND NUTRITIVE VALUE OF MILKS

The milks of all species are similar in that they are all mixtures of similar chemical substances, including fat, lactose (milk sugar), proteins, vitamins, inorganic salts, and water. Yet there are marked species differences in all milks, the most apparent of which are in the relative proportions of the various constituents. Abderhalden (*4*) directed attention to a relationship between the concentration of protein and minerals in the milks of different species and the length of time required for the young of the species to double their birth weight. The data he compiled to illustrate this relationship indicate that the more rapid the rate of growth and development of the young, the greater is the concentration of protein and minerals needed in the milk.

The percentage composition of the milks of the six species with which this discussion is concerned are given in table 2. The quantitative differences in the chemical composition of the different milks are obviously of considerable importance in meeting the nutritive requirements of the young. If one can assume that normal milk of the same species is the best food for the nutrition of the young, then the carbohydrate-fat-protein ratio in each milk is probably one particularly favorable to the digestion and metabolism of the food factors required by the suckling of that species.

TABLE 2.—*Average composition of different milks*

Species	Water	Protein	Fat	Lactose	Ash	Species	Water	Protein	Fat	Lactose	Ash
	Percent	*Percent*	*Percent*	*Percent*	*Percent*		*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Horse [1]	89.04	2.69	1.59	6.14	0.51	Sheep [4]	82.90	5.44	6.24	4.29	0.8
Cow [2]	87.90	3.13	3.65	4.50	.72	Pig [5]	82.02	6.22	6.77	[6] 4.02	.97
Goat [3]	87.14	3.71	4.09	4.20	.78	Dog [7]	80.1	[8] 7.3	8.5	2.8	1.3

[1] Linton (*686*).

[2] White (*857, p. 56*).

[3] Frahm (*381*).

[4] Weiner (*1198*).

[5] Hughes and Hart (*557*).

[6] Difference between total solids and proteins+fat+ash.

[7] Linton (*688*).

[8] Difference between total solids and fat+lactose+ash.

Campbell, publishing in collaboration with Supplee and Ware (*188*), has stated that the carbohydrate-fat balance tolerated by young puppies has a very narrow range, particularly in artificially fed puppies. There is evidence that the limits of the carbohydrate-fat ratio tolerated by the young of other species is much wider. Linton (*686*), analyzing milk from 142 mares, observed that those foals receiving milk abnormally low in lactose, a carbohydrate, appeared malnourished, whereas milk somewhat high in lactose was well tolerated. Variations in fat, on the other hand, unless the fat content of the milk was quite high, seemed to be without influence on the condition of the foal. Ritzman (*970*) made some observations on the relation between the fat content of ewe's milk and the weight increase in lambs on the different milks. He found a considerable fluctuation in rate of weight increase, but it bore no definite relationship to the percentage of fat in the milk. He concluded from his practical observations that a quantitative variability in milk fat is not significant in the nutrition of lambs so long as the demands for protein, minerals, and vitamins are met. The excellent results reported by Converse and Meigs [3] and by Archer, Archer, Bond, and Dunlop (*27*) from the feeding of calves on skim milk plus cod-liver oil show that the carbohydrate-fat ratio well tolerated by the calf has very wide limits.

While it is evident that the amount of fat in the ration of the suckling foal, calf, and lamb may be considerably reduced below the average of fat in the normal milk of the respective species without unfavorable effects on the sucklings, it seems that some milk fat is necessary in the ration of the growing animal to supply the essential fat acids or fat-acid compounds necessary for growth and to serve as a medium for fat-soluble vitamins.

Lactose serves as a source of energy in the ration of the young animal. It also plays a part in the utilization of calcium and phosphorus. French and Cowgill (*393*) have shown that in the immature animal lactose has a definitely favorable influence on the utilization of calcium and phosphorus. There is some indication that the ratio of protein to lactose is an important factor in this role of lactose, since a favorable effect on calcium metabolism is obtained from lactose in parathyroid tetany (*574*), a disease condition marked by a low level of calcium in the blood, only if the ratio of protein to lactose does not go above 4 parts of protein to 1 part of lactose, or below 2 parts of protein to 25 parts of lactose.

There are other differences in milk the importance and significance of which are not so obvious as are differences in the percentages of constituents. Differences in such factors as the physical state of the fat, the size and toughness of the curd formed, and the capacity of the milk to resist change in acidity with the addition of acid or alkali may be important in the digestion of the milk. Again, differences in the composition of the various constituents themselves may be of as great significance as differences in their concentration.

Milk fat has characteristic physical properties and fat-acid composition for each species. It is to be expected that it also differs in biological properties.

Milk proteins likewise vary with the species in chemical composition and in immunological properties. Usually an immunological or defensive reaction occurs when a protein from one species is introduced into the blood stream of an animal of an unrelated species. When such a reaction is produced the protein causing it is designated as antigenic. Milk proteins are antigenic, some producing more marked antigenic reactions than others. The term "milk proteins" includes at least three chemically distinct proteins—casein, lactalbumin, and lactoglobulin. These three proteins vary by species in their ratios to each other. Casein, which is found only in milk, forms the bulk of the protein in that of most domestic species. Though the caseins of all species are rather closely related immunologically and are similar in chemical composition, species differences, though not great, do exist. Lactalbumin also is a protein found only in milk, although it is somewhat similar to the serum albumin of the same species. The lactalbumins of different species are distinct and different. Lactoglobulin has been shown to be identical with serum globulin of the same species and, like the serum globulin, to differ with species.

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[3] CONVERSE, H. T., and MEIGS, E. B. VITAMIN REPLACES WHOLE MILK IN THE CALF RATION. U. S. Bur. Dairy Indus. Leaflet 731, 3 pp. [Mimeographed.]

These three milk proteins differ from each other in their value as body-building material. Osborne and Mendel (*882*, *883*) have shown that the fraction of milk proteins containing lactoglobulin and lactalbumin is utilized much more efficiently in the growth of young animals than the casein fraction. That milk proteins as a whole are more efficient than vegetable proteins has been indicated by data from many experimenters.

In the feeding of milk of one species to the young of another the potential effects of the antigenic differences in the milk proteins are often overlooked. It has long been recognized that in general the young of one species thrive better on milk of their own kind than on that of another species. Furthermore, the sooner after birth the milk of another species is substituted for milk of the same species, the more unfavorable is the outlook for the young animal. The results of some studies published by Bilek (*100*) are cited as indicating that some of the unfavorable effects so often obtained from feeding milk of another species may well be attributed to qualitative rather than quantitative differences. In these experiments, cow's milk and goat's milk were fed to the young of several species. The different species did not react alike. Kids used both milks equally well, while calves reacted to goat's milk with severe gastrointestinal disturbances which lasted as long as goat's milk feeding continued. Pigs showed no disturbance on cow's milk but reacted to goat's milk in a fashion similar to that observed in the calves. Foals showed a stubborn diarrhea when fed undiluted cow's milk but not the slightest disturbance on goat's milk. Since the two milks are very similar in percentage composition, the results indicate the presence in the milk of substances incompatible or toxic to the animals that reacted unfavorably. It is suggested that the incompatible factors are proteins.

It is known that the presence of a foreign protein undigested in the circulating blood is more or less toxic to an animal and may produce a sensitization to further additions of the foreign protein. It has been established that the newborn animal normally absorbs considerable protein undigested through the gastrointestinal wall. Although this apparent permeability decreases rapidly after birth, it probably does not cease abruptly, since, as Ratner (*948*) has shown, it still occurs to some slight extent in about 50 percent of adults. The possibility of the absorption in the very young suckling of appreciable amounts of undigested and sensitizing foreign protein might be a major factor in the incompatibility of the milk of one species for the young of another.

PRACTICAL POINTS ON THE FEEDING OF SUCKLING ANIMALS

Whether a newborn animal is to be suckled by its dam or by a foster mother or is to be fed by hand, it should if possible receive colostrum of its own species. When this is not available serum of its own species is suggested as the substitute most likely to be successful in protecting the animal against disease. Since normal serum for feeding is not at present readily available as a commercial product, the farmer or stockman will probably require the services of a veterinarian in the preparation of blood serum from adult animals for use as a colostrum substitute. This serum may be fed with milk, it may be injected, or it may be administered in both ways. Only sterile serum should be injected, of course. It is important that the protective food, whether colostrum or serum, be fed as soon as possible after birth, since the protection it confers is probably needed within the first few hours.

FREQUENCY OF FEEDING

Where a system of hand feeding is to be employed, the frequency of feeding is an important factor in its success. The young pig left with the sow has been observed to suckle 24 times within 24 hours, the young foal 20 times in the same interval. Calves, kids, lambs, and puppies probably suckle with a similar frequency. Thus the nutritive requirements of the young animal are met naturally by small quantities frequently supplied. Such frequency is obviously impractical in hand feeding. It has been found that calves, after the period of colostrum feeding, do quite well on two or three feedings a day. Newborn foals, kids, lambs, and pigs have done very well when started on five feedings a day. This schedule was arbitrarily adopted with good results in some feeding experiments carried out at the Animal Husbandry Experiment Station at Beltsville, Md. Equally good results may perhaps be obtained with less frequent feedings. The five daily feedings may certainly be reduced to four within 4 or 5 days, and to three within 2 weeks. Frequent feeding is much more important during the first few days after birth, while the animal is making its adjustment to a new environment, than at a later period.

FEEDING CALVES

The methods in use in the feeding of calves may be enumerated as follows: (1) Suckling by dam; (2) feeding whole milk; (3) feeding skim milk or separated milk; (4) feeding reconstructed dried skim milk, that is, with water added; (5) feeding calf meals or gruels with a minimum amount of liquid milk (fig. 1). Unless the cow dies or is diseased every calf should be left with its dam from 1 to 4 days to receive colostrum. With calves from dairy cows whose milk is marketable, unless the calf is a very valuable animal from the breeding standpoint, it is practical to substitute as soon as possible a less expensive food for either a part or all of the whole milk. In such cases the general practice seems to be to feed whole milk for the first 2 weeks. Beginning about the third week whole milk may be gradually replaced with the milk substitute, which may be fresh skim milk, reconstructed dried skim milk, or some form of calf starter, either a gruel or a dry meal. For general directions for feeding management of dairy calves the reader is referred to Department of Agriculture Farmers' Bulletin 1723 (*1037*) and to the article beginning on page 597 of this yearbook.

Contrary to the general belief that calves should receive whole milk for the first 2 weeks at least, Converse and Meigs[4] found that dairy calves fed skim milk supplemented with cod-liver oil beginning the fourth day after birth were indistinguishable in general appearance after the first month from calves that had received equal amounts of whole milk for the first 20 days and skim milk thereafter. Archer, Archer, Bond, and Dunlop (*27*) also have reported good results from feeding, beginning the fourth day after birth, of 1 gallon of separated milk plus 1 tablespoonful of cod-liver oil daily. This amount of milk was increased to 1½ to 1¾ gallons by the third week. Meadow hay and a meal mixture of 4 parts of flaked maize and 1 part of linseed cake were made available after the first week.

Figure 1.—Calves, like other young animals, do best on their mothers' milk, but they can be successfully raised by careful hand feeding.

Dried skim milk can be reconstructed and fed; in this form it is apparently as good as fresh skim milk in calf feeding. It has the further advantage that at an early age it can be fed dry in a meal. Knott, Hodgson, and Ellington (*640*) have reported that a group of experimental calves weaned at 5 to 6 weeks from reconstructed skim milk to a dried skim-milk meal were healthy and vigorous, and at the age of 6 months were indistinguishable from heifers raised on separated skim milk.

Calves begin to supplement a milk diet by nibbling at other feeds when 2 or 3 weeks old. For a description of calf starters or calf meals the reader is referred to the New York (Cornell) Agricultural Experiment Station Bulletin 622 (*1012*).

It is of interest that attempts to raise calves on diets of milk alone have consistently failed. In some experiments reported by Herman (*510*) calves fed exclusively on whole milk appeared practically normal for about 6 months, but when the exclusive milk diet was continued beyond this period, became increasingly anemic and died within a few months thereafter. With the addition of iron, copper, manganese, and cod-liver oil to the ration the period of growth was prolonged and the calves lived about a month longer than those receiving milk alone.

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[4] See footnote 3, p. 507, for reference.

FEEDING FOALS

Since in this country mare's milk commonly has no value as a marketable product, it is the cheapest feed for the young foal as well as the best that can be provided (fig. 2). The suckling period of the foal varies widely with custom in different localities, with the availability of other feeds for the foal, and with the use which it is desired to make of the mare. According to Ehrenburg (*312*), in certain sections of Germany foals are always separated from the dam at 3 months, while in Spain it is the custom to allow them to suck for 9 or 10 months. In old Rome the foal was often permitted to suckle for 2 years. The first 6 months of the foal's life constitute the period of most rapid growth and development, and the nutrients most suitable for this growth should be supplied to him during this time. Especially where there is a shortage of good feed, the foal should be permitted a suckling period of fully 6 months or longer, since the mare is better able to utilize poor food. Where the mare is required for heavy work or is being used to produce another foal, the suckling period may possibly be reduced

Figure 2.—The foal gets the best and cheapest food from its mother for the first 6 months of its life.

to 3 or 4 months without retarding the development of the foal if an ample supply of other suitable feeds is available. In such cases, fresh cow's milk, whole, or preferably skimmed, has been fed after weaning with good results. Dried skim milk mixed with the grain can also be used to advantage.

Hand-fed foals are sometimes fed fresh cow's milk modified as follows: One-half to two-thirds cow's milk, the other half or third water, with 1 tablespoonful of sugar to every pint of mixture. Cow's milk thus modified roughly approximates mare's milk in the concentration of fat and sugar, although protein and minerals are low. Whole cow's milk is usually unsuited to very young foals, perhaps partly because of its fat content. The following mixture of dried cow's milk has been used with excellent results: Dried whole milk, 8.69 percent; dried skim milk, 5.49; sugar, 3.9; lime water, 6; and water for mixing, 76.2 percent. In this mixture the concentration of total solids exceeds that in mare's milk, but the proportions of carbohydrate, fat, and protein are approximately the same.

The quantity of milk supplied by a mare to her foal 4 to 6 weeks after birth has been estimated at figures varying between 4 and 35 quarts a day. According to Blechschmidt (*127*) a draft mare should give 18 or more quarts and a mare of one of the lighter breeds 10 to 12 quarts daily. A foal will require 4½ to 6 quarts of mare's milk for each 100 pounds of its own weight until such time as it is eating an appreciable quantity of supplementary feed. Three to four quarts of the dried-milk mixture described in the previous paragraph will supply approximately the same amount of energy as 4½ to 6 quarts of mare's milk.

It should be mentioned that, while little is known of their vitamin requirements, unless foals have access to green pasture or to good-quality alfalfa hay, it seems advisable to include some cod-liver oil in their ration.

The foal begins nibbling grain and hay about 3 weeks after birth. Crushed or ground oats or bran are good feeds for him to start on. A mixture of 2 parts of cracked corn, 4 parts of crushed oats, 2 parts of bran, and 1 part of linseed meal is also excellent. The foal should be eating approximately 0.5 pound of grain per 100 pounds of body weight daily at 3 months and twice this much at weaning time. Good legume hay should be made available as soon as the foal will eat it.

FEEDING KIDS

Goat kids, after the colostrum feeding period, apparently do equally as well on whole cow's milk as on whole goat's milk. Where comparative feeding tests have been made with the two kinds of milk, the differences in results have been attributed to differences in the energy values of the milks. That is, the animals on the richer milk made slightly greater gains.

In a herd of dairy goats, the kids are customarily removed from the does after the colostrum feeding period and thenceforth are hand-fed from bottles (fig. 3), or preferably from pails. The milk fed may be either goat's or cow's. Kids grow well when fed 24 ounces of milk daily, given in four feedings, during the first week. This amount is increased gradually until the kid is receiving approximately 64 ounces at 10 weeks of age. At 4 weeks alfalfa hay and a grain mixture of 4 parts of ground corn, 2 parts of oats, 1 part of bran, and ½ part of linseed meal are made available. As the kids consume more grain and hay the amount of milk may be decreased.

Kids are sometimes milk-fed for 5 months, but this seems unnecessarily long. A milk-feeding period of 3 months, as is customarily followed in feeding lambs, is probably quite sufficient. There seems to be no reason why the amount of whole milk consumed by kids cannot be reduced as in the case of calves by substituting fresh skim milk or dried skim milk for whole milk at an advanced stage in the milk-feeding period.

Figure 3.—Kids do well when hand-fed on cow's milk.

FEEDING LAMBS

Lambs are usually allowed to run with their dams until they are 3 to 5 months old (fig. 4). They begin to nibble at feed from 10 to 16 days after birth. Unless the lambs are dropped after the pastures are ready, it is good practice to supply hay and grain in a small enclosure accessible to the lambs but inaccessible to the ewes. Green alfalfa hay is excellent roughage. A grain mixture which has been recommended by the Ohio Agricultural Experiment Station (*464*) for lambs that are to be marketed consists of 5 parts of corn, 2 parts of oats, 2 parts of bran, and 1 part of linseed meal.

Orphan lambs, once the needs occurring during the colostrum period are satisfied, can be raised without difficulty on whole cow's milk, whole goat's milk, or a 20-percent mixture of dried whole cow's milk in water. Practical directions for feeding the orphan lamb are given in some detail in California Agricultural Extension Service Circular

49 (*791*). In some feeding experiments carried out at the Animal Husbandry Experiment Station at Beltsville (*406*), in which dried-milk mixtures were used to replace ewe's milk, a 20-percent dried whole-milk mixture, which has the same energy value as ewe's milk, was found to give excellent results as a substitute for ewe's milk, but dried skim milk, even when supplemented with cod-liver oil, was found quite unsatisfactory.

Lambs should be fed milk for at least 3 months. Frequent feeding of small amounts during the first 3 or 4 days is essential. Small lambs, weighing from 5 to 7 pounds, should receive about 1 pint or a little more a day. Larger lambs, 8 to 12 pounds in weight, require 1½ to 2 pints a day. The total quantity of milk should of course be increased somewhat as the lambs increase in size. It has been shown (*406*) that lambs can make excellent growth on the following weekly allowance of dried whole milk, which is fed as a 20-percent mixture with water: At 1 week, 3.6 pounds of dried milk per 100 pounds of live weight; at 2 weeks, 2.6 pounds; at 3 weeks, 2.5; at 6 weeks, 2.1; at 8 weeks, 1.3; and at 10 weeks, 0.9 pound.

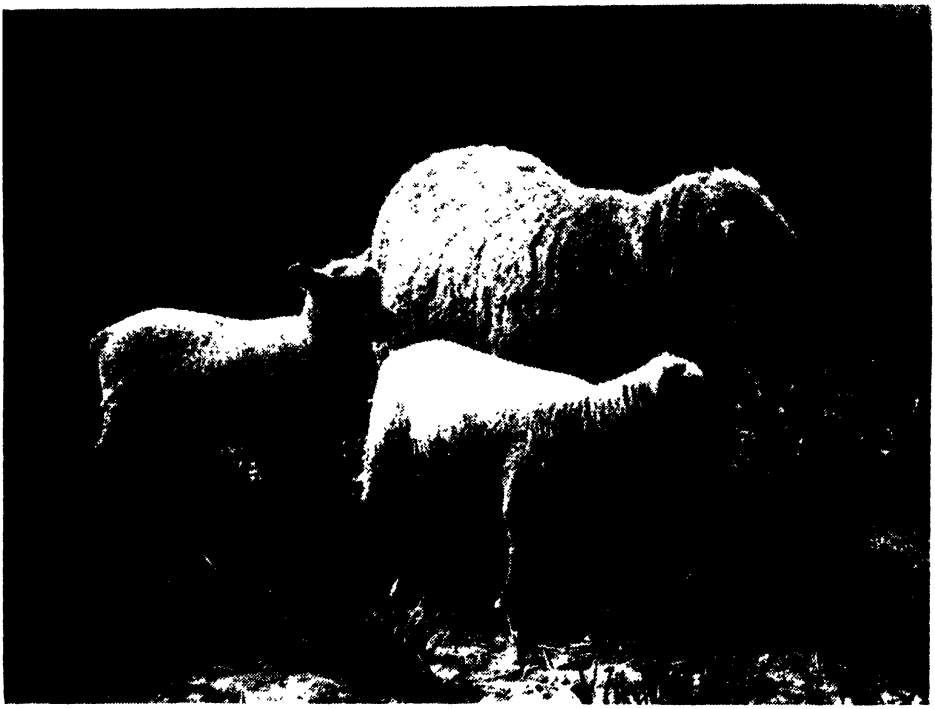

Figure 4.—**Lambs 10 to 16 days old nibble at feed, but they need milk from the ewe for 3 to 5 months. The lambs shown are twins.**

FEEDING PIGS

For the first 3 weeks of life pigs live exclusively, except for the small amount of mineral matter picked up from the soil, on sow's milk (fig. 5). Usually they begin eating a little grain from the sow's trough at 3 weeks, unless a special creep is provided for them, but their most important feed is still sow's milk until they are weaned at 8 or 12 weeks. The average birth weight of a pig is doubled within 7 to 10 days. This is possible only because sow's milk is a more concentrated food than cow's milk and is supplied to the little pig in relatively liberal amounts. Thompson (*1134*) has reported, as the result of a study of the effect of milk consumption on the growth of pigs, that the average daily milk consumption of the pigs he observed varied from 0.226 to 0.505 pound per pig. Pigs receiving the greatest amount of milk made the greatest gain even after weaning. Schneider (*1016*) has estimated that 1.534 pounds of sow's milk is required for each pound of live-weight gain the pig makes during the first 8 weeks of the suckling period. The figure for average daily milk yield of sows varies widely with such factors as breed, size of litter, and nutrition. Published estimates have ranged from 4.5 to 18 pounds of milk a day.

Figure 5.—Pigs double their weight within 7 to 10 days on the sow's milk. The pigs that get the most milk make the greatest gains, and continue to do so even after weaning at 8 or 12 weeks.

The daily milk yield of the sow reaches its maximum during the third or fourth week of lactation. From this time on she can no longer entirely satisfy the nutritive requirements of the pigs and it becomes necessary to supplement her milk with other feed. This supplemental feed may be supplied as a mixture consisting of 80 percent ground grain and 20 percent protein supplement; or if the self-feeding system is employed, shelled corn may be provided in one compartment of a feeder, a protein supplement in another compartment, and a mineral mixture in a third. The protein supplement may be fish meal, tankage, linseed meal, shorts, or middlings, which should be combined with alfalfa meal in a ratio of 3 parts of supplement to 1 part of alfalfa meal. A combination of animal and plant proteins may also be used as in the so-called trinity mixture, made up of 2 parts of tankage, 1 part of linseed meal, and 1 part of alfalfa meal. The inclusion of a good grade of alfalfa meal in the ration is especially important where pasture is not the best.

The following mineral mixture has been found satisfactory:

	Parts		*Parts*		*Parts*
Bonemeal	38	Sodium chloride	20	Copper sulfate	0.25
Calcium carbonate	39	Ferrous sulfate	2.5	Potassium iodide	.03

The mineral mixture may either be provided in a separate compartment of the self-feeder or it may be combined with the protein-supplement mixture in the proportion of 5 parts of mineral mixture to 100 parts of protein mixture.

Unless there is some special reason for doing so, pigs should not be weaned earlier than 8 weeks after birth. They are sometimes left with the sow as long as 12 weeks. A suckling period of 60 days is a good practice.

Studies on the raising of orphan pigs on whole cow's milk and on modified cow's milk have been carried out on pigs 12 days or more old. The investigations of Washburn and Jones (*1183*) indicated that cow's milk with a relatively low fat content was satisfactory for young pigs 4 to 5 weeks old. Evvard, Glatfelter, and Wallace (*353*) fed several small groups of young pigs from 12 to 72 days of age on cow's milk and on cow's milk plus various protein supplements. The number of pigs with which they worked was small and their results were complicated by diseases probably due to vitamin deficiencies, but the results indicated that cow's milk supplemented by 1 to 3 percent of casein can be used in place of sow's milk after the pigs are 2 weeks old. Pigs so fed should, however, have access to green pastures as well as to grain and a mineral mixture as soon as they will eat.

The occurrence of nutritional or milk anemia among suckling pigs is an important factor in the mortality of pigs before weaning time. Most young animals are supplied at birth with sufficient stores of iron and copper to supplement the deficiencies of these elements in milk until such time as they begin eating solid food. The young pig seems to be exceptional in that he usually develops anemia within 2 weeks after farrowing when restricted to a diet of milk alone and denied access to dirt or sod. The disease can be entirely prevented by the inclusion of a very small quantity of soluble iron and copper salts in the milk diet.

The following are some practical methods that are in use for the prevention and cure of milk anemia in young pigs: (1) Placing soil or sod in pens; (2) painting a solution of iron and copper on the sow's udder daily; (3) a weekly dose of 180 milligrams of iron and 25 milligrams of copper; (4) the incorporation of a mineral mixture in a pig creep to be used from the time the pigs are 8 days old.

FEEDING PUPPIES

Except in breeds such as the Alsatian, in which lactation is said to cease about 4 weeks after parturition, the pups of normal healthy bitches are usually suckled for 6 weeks, sometimes for 8. In order that the transition to other foods may be gradual, supplementary feeding should be started while the puppies are still receiving milk from their dams. When puppies are to be weaned entirely at 6 weeks, it is well to begin feeding some solid food at 3 to 4 weeks after birth. It is recommended that at this time the pups be offered daily small amounts of chopped or ground lean meat and some dry bread, dry cereal, or puppy biscuit which has been moistened with milk or broth (fig. 6).

Spaulding (*1092*) recommends feeding one-half teaspoonful of raw scraped beef once a day for 2 or 3 days beginning at 3 or 4 weeks of age. This amount is then fed twice a day and the number of feedings increased at 3-day intervals to three and then to four times a day. When meat is fed four times a day an equal quantity of dry cereal or puppy meal should be added to it. A drink of cow's milk or a milk substitute may be given twice a day throughout the remainder of the suckling period. When the puppy has been taught to eat such foods before weaning, unfavorable effects on rate of growth after separation from the dam will probably not be noticeable.

Figure 6.—**Puppies should be started on solid feed before they are weaned to prevent unfavorable effects on rate of growth after weaning.**

The artificial existence imposed on pets may result in a lack of of exercise and probable deficiencies in nutrition, in some instances with impairment of reproductive functions to the extent that the bitch produces either an insufficient supply of milk or even unsuitable milk. In such cases as well as in those in which puppies are orphaned at birth, it is necessary to feed some substitute for the dam's milk. The usual experience has indicated that unless the animals receive colostrum from the dam, the success of any hand-feeding procedure is doubtful. Whether this is due to the incompatibility of the substituted milk that has been used or to a need for the immunizing bodies present in the colostrum is undetermined.

Fresh cow's milk is not satisfactory for feeding very young puppies, partly at least because the concentration of protein, fat, and minerals in cow's milk is so much lower and the sugar so much higher than it is in bitch's milk. Canned condensed milk has sometimes been used with success after the puppies are 3 to 4 days old. Whole dried milk may also be used by combining 20 parts by weight of milk with 80 parts of water. Another mixture sometimes recommended consists of whole cow's milk, either fresh or reconstructed from dried milk, to which has been added half its volume of raw egg yolk. Still another mixture, suggested by Spaulding (*1092*), is made by combining 2¼ teaspoonfuls of cream and 2½ teaspoonfuls of casein with 4 ounces of milk. The same author recommends that puppies receiving a substitute milk be fed every 2 hours during the day and every 3 hours during the night for the first week. These intervals may be increased to 3 and 4 hours during the second week.

With artificially fed puppies, the supplementary feeding may be started in the third week.

NUTRITIONAL REQUIREMENTS OF BEEF AND DUAL-PURPOSE CATTLE

by W. H. Black, Bradford Knapp, Jr., and J. R. Douglas[1]

THIS article summarizes a good deal of the existing material on the needs of beef animals for energy, protein, minerals, and vitamins. Conflicting viewpoints are given and some of the gaps in our knowledge are clearly indicated. The discussion is more or less technical in nature.

A KNOWLEDGE of nutritive requirements for energy, protein, minerals, and vitamins is essential for the economical production of beef or of beef and milk. A substantial portion of the feed of cattle is utilized in the maintenance of body tissues and normal body functions. Additional amounts are required for utilization in growth, fattening, reproduction, or lactation. This article will consider the need for the various nutritive elements in relation to these functions in beef animals.

The discussions on the requirements of beef cattle for energy, protein, minerals, and vitamins also apply to dual-purpose cattle that are not lactating or are kept primarily for beef-production purposes. For lactating and pregnant cows of the dual-purpose type, kept primarily for dairy purposes, the various nutritional requirements as given for strictly dairy cows (in the article, p. 566) should be applicable.

ENERGY REQUIREMENTS OF BEEF CATTLE

FOR MAINTENANCE

A relatively large portion of the feed consumed by beef cattle, whether the animals are being fed for growth, fattening, reproduction, or wintering, is used in maintaining the normal body functions. This demand for food is referred to as the maintenance requirement; it is the amount of food required to maintain the tissues of an animal that is not growing, fattening, or reproducing. If there is not enough food, as frequently happens under winter-range conditions, the needs of the body are met by breaking down of tissue, with a resultant loss in weight. The maintenance requirement varies among animals of different breeds, sexes, and weights. A knowledge of the maintenance requirements of beef cattle is of considerable importance in the economical production of beef.

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Fasting catabolism is used as the basis for determining the maintenance requirements of all warm-blooded animals. This is the breaking down of body tissue which takes place in the absence of food to supply the nutrients required to maintain the normal body functions. Fasting catabolism is measured by the use of a respiration calorimeter which measures the energy used by the animal while receiving no food—in other words, the energy furnished by the break-down of the body tissues. It was found by many investigators that the energy required was in some way proportional to the weight of an animal. Later investigation suggested that the energy was not directly proportional to weight but rather to some function of body weight. While this relation holds in general, many deviations arise from specific body activities. Brody (*157*)[2] has shown by investigation that the surface area of an animal and its weight are closely related and that this relationship may be expressed mathematically.[3] By using this mathematical relationship, the average requirement for cattle of any weight may be computed. The standard as proposed by Brody is shown in table 1.

TABLE 1.—*Daily amounts of total digestible nutrients required for maintenance of cattle, as proposed by Brody (157) and by Morrison (819)*

Weight of animal (pounds)	Requirement according to Brody	Minimum requirement, according to Morrison for—			
		Dairy cattle	Wintering beef calves	Wintering beef yearlings	Wintering beef cows
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*
100	1.26				
200	2.09				
300	2.80		3.9		
400	3.46		4.8		
500	4.07		5.7		
600	4.65		6.5	6.3	
700	5.21	5.13		7.0	
800	5.74	5.77		7.7	
900	6.25	6.38			6.9
1,000	6.75	7.00			7.5
1,100	7.24	7.60			8.0
1,200	7.71	8.20			8.6
1,300	8.18	8.80			
1,400	8.63	9.39			
1,500	9.08	9.96			
1,600	9.52	10.54			
1,700	9.95	11.11			
1,800	10.37	11.68			
1,900	10.79				
2,000	11.20				

Another method of determining maintenance requirements for cattle is by the use of data obtained in feeding experiments. In its simplest form, this method involves the determination of the amount of food required to maintain mature animals at a constant weight. If, by trial and error, the experiment is successful in maintaining a constant live weight over an extended period, a fairly accurate measure of the maintenance requirement would be obtained, provided constancy of live weight implies a constant energy content of the tissues of the body. In young growing animals, for example, an increase in bone and muscle tissue may take place under weight-constant conditions, the increase being made at the expense of other tissues. Nevertheless, feeding standards based on this method have been in common use for many years. Armsby (*30*), Wolf-Lehman, and later Morrison (*819*) proposed feeding standards all based on this trial method. In table 1 are shown the feeding standards of Morrison in comparison with those of Brody. It will be noted that the Morrison standard is slightly higher.

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[2] Italic numbers in parentheses refer to Literature Cited, p. 1075.

[3] It is believed that the surface area varies with the two-thirds to three-fourths power of the weight. Brody suggests the 0.734 power of weight. Thus Brody's equation is $Q=70.5M^{0.734}$, in which Q is the calories per day and M is the body weight in kilograms. A conference of workers of the National Research Council on energy metabolism[4] has recommended that the factor, body weight raised to the 0.73 power, be tentatively adopted as the base of reference for computing fasting heat production and the endogenous nitrogen metabolism.

[4] NATIONAL RESEARCH COUNCIL, COMMITTEE ON ANIMAL NUTRITION. REPORT OF THE CONFERENCE ON ENERGY METABOLISM HELD AT STATE COLLEGE, PA., JUNE 14–15, 1935. . . . 93 pp. 1935. [Mimeographed.]

FOR GROWTH AND FATTENING

Growth and fattening in beef cattle are in most instances simultaneous and are therefore not easily separated. Growth is attained in several ways—by increase of skeleton size, by muscular increase, by fattening, etc. In beef cattle, only 3 to 4 percent of the mature weight of an animal is attained at birth, as compared with more than 50 percent of the skeletal size and about 70 percent of the length of leg. Thus, there are different rates of increase and ages of maturity for various factors of growth. With growth and fattening, there is a change in the percentages of water, fat, protein, and bone.

The first requirement of a fattening ration is that it contain an abundance of energy. Unless a surplus of energy above maintenance is supplied, growth and fattening are impossible. Thus the limit on the energy required for fattening is the quantity of energy-producing food that the animal can consume. Kleiber (*634*) proposed the following equation to express the relationship between quantity consumed and energy returned in the product:

> Energy in product equals total energy in food consumed, minus energy in feces, minus energy in urine and in methane,[5] minus heat increment of food, minus fasting catabolism.

Thus, for fattening an animal, total energy consumed must be increased to as large an amount as the appetitite of the animal will allow. The greatest efficiency of feed utilization has been found, however, in feeding at a rate slightly below the maximum capacity to eat. Experiments by the Bureau of Animal Industry and by various State stations have clearly shown that feeding below the highest level resulted in slightly increased efficiency from the standpoint of animal gains; but from the standpoint of energy return, the full-fed steers made the greatest return per unit of feed, owing to their greater fatness.

Since gains are determined by the capacity to consume, the question arises as to the quantities that can be consumed by steers. Brody and others have shown that the size of the digestive organs in cattle varies with the surface area rather than with the weight. However, there are many factors other than size of stomach and intestines that determine capacity to eat, or appetite. The best measure of capacity may be by self-feeding steers to determine the quantity that they will eat. It is believed that in most of the reports on self-feeding steers one of the most important points is ignored by investigators— they fail to report feed consumption by periods. In figure 1 is shown the consumption by self-fed versus that by hand-fed steers in two experiments.[6] It should be noted that in both experiments the self-fed steers ate more feed earlier and less feed in the later periods, while the hand-fed steers were fed according to common practice with increasing amounts

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[5] Methane is a constituent of marsh gas produced in the rumen by the action of certain micro-organisms.

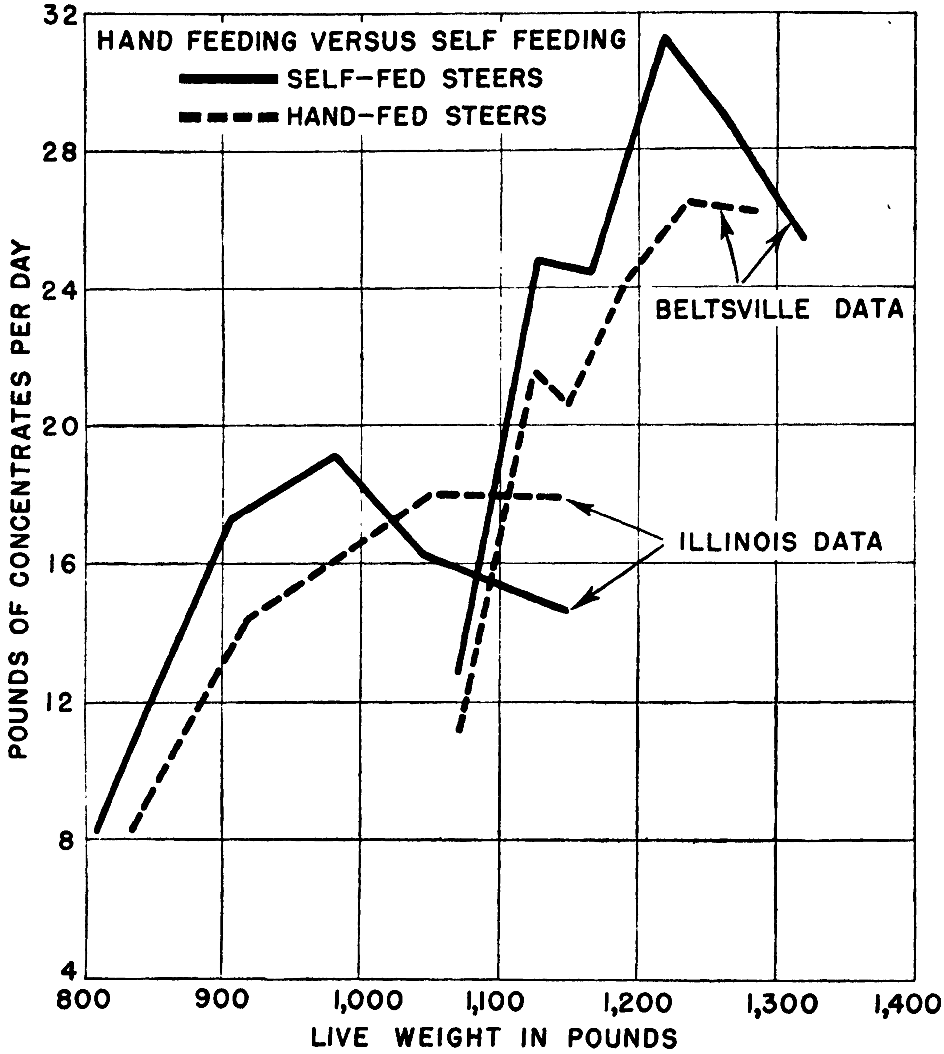

Figure 1.—Quantities of concentrates consumed per day by growing steers in self-fed and hand-fed groups, in experiments at the Illinois Agricultural Experiment Station and at Beltsville, Md.

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[6] One experiment was conducted at the Illinois Agricultural Experiment Station (*829*), the other at Beltsville, Md., by the Bureau of Animal Industry (data unpublished).

of concentrates. If the natural appetite of cattle leads to consumption of concentrates on a curve of the type shown for the self-fed groups, should not hand-feeding follow a similar curve? This point is in need of further investigation.

Experiments by the Minnesota and Missouri Agricultural Experiment Stations have shown the body composition of steers at various ages during growth and fattening. These data show that the per-

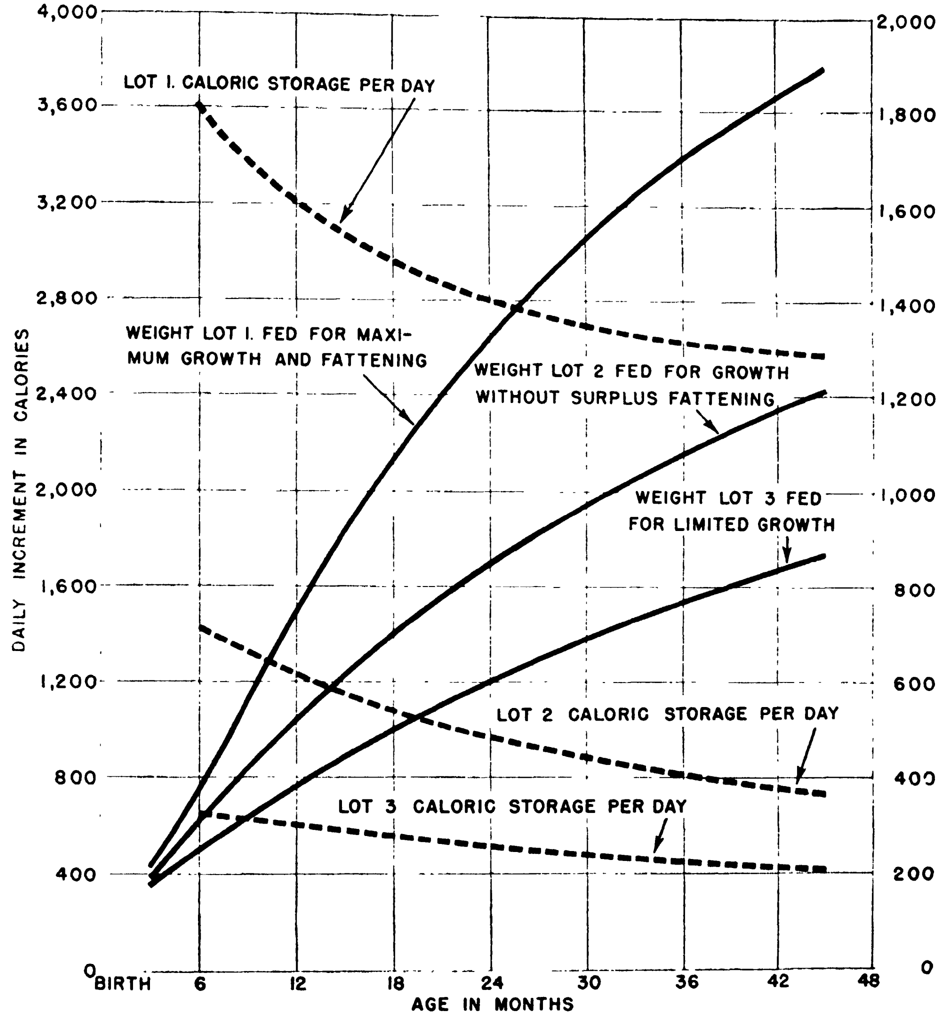

Figure 2.—Average live weight and daily increment of calories for beef steers on three planes of nutrition.

centages of protein and water steadily decrease as the animal matures, while the percentage of fat increases steadily from birth to maturity. The percentage of ash decreases very gradually from birth to 1,500 pounds (table 2). Data from the Missouri experiment (*825*) show an increase in the percentage of fat, a decrease in the percentage of bone, and an early increase followed by a more rapid decrease in the percentage of lean meat. In figure 2 are shown the average weights of three groups of steers fed on three planes of nutrition, and the average daily storage of calories, or energy, during the same period. It should be noted that in group 1 the rate of gain is much greater than in the other two lots, and the storage of calories of group 1 tends to parallel that of the other lots, though at a much higher level. Group 1 was fed for maximum growth and fattening, and the less rapid decrease in caloric increment is probably due to the higher caloric value of fat in comparison to lean meat. However, the fact that 1,600 calories are stored each day by an animal does not mean that by feeding 1,600 calories above maintenance this amount would necessarily be stored. The amount of food required for this storage level may exceed the amount stored by two or three times.

Table 2.—*Average composition of steers at various stages* [1] *of growth*

Normal weight (pounds)	Steers	Water	Dry matter	Protein	Fat	Ash
	Number	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
100	5	71.84	28.16	19.89	4.00	4.26
200	4	70.43	29.57	19.14	6.01	4.42
300	4	65.72	34.26	18.77	11.19	4.30
400	5	65.79	34.21	19.31	10.56	4.34
500	5	62.90	37.10	19.15	13.73	4.22
600	3	61.20	38.80	19.40	15.04	4.36
700	4	60.35	39.65	18.60	16.58	4.48
800	3	58.44	41.56	18.80	18.52	4.24
900	3	54.10	45.90	17.66	24.08	4.16
1,000	4	52.03	47.97	17.11	26.91	3.95
1,100	3	47.77	52.23	16.38	32.03	3.82
1,200	3	47.96	52.04	16.02	32.32	3.70
1,300	2	47.93	52.07	15.79	32.50	3.78
1,400	1	47.76	52.24	16.15	32.58	3.51
1,500	1	43.48	56.52	15.72	37.59	3.21

[1] Not including contents of the digestive tract. From Morrison (*819, p. 152*).

Morrison (*819*) has proposed a standard for fattening and growing beef cattle, based on experience in many feeding trials. In table 3 is shown the standard as proposed by Morrison. Results of feeding trials by the Bureau of Animal Industry tend to show that this standard is in general adequate, though the upper figure for each weight may be exceeded.

Table 3.—*Total digestible nutrients required daily per head for growth and fattening of beef cattle, as proposed by Morrison (819)*

Live weight (pounds)	Growing beef cattle fed liberally for rapid growth	Calves being fattened for baby beef	Fattening yearling cattle	Fattening 2-year-old cattle
	Pounds	*Pounds*	*Pounds*	*Pounds*
100	1.2- 2.0			
200	3.4- 4.2			
300	5.2- 5.9			
400	6.6- 7.2	7.4- 9.8		
500	7.6- 8.5	9.0-11.4		
600	8.5- 9.6	10.6-12.9	10.3-12.7	
700	9.2-10.7	12.0-14.2	12.0-14.4	
800	10.0-11.8	13.1-15.2	13.5-16.1	
900	10.8-12.9	13.8-15.8	14.8-17.4	14.6-17.4
1,000	11.4-13.9		15.9-18.5	16.0-18.8
1,100			16.9-19.5	17.0-19.6
1,200				17.7-20.1

There is need for further experimentation to determine the eating capacity, the nutrients required for fattening, and the method of feeding for greatest economy in beef production.

PROTEIN REQUIREMENTS OF BEEF CATTLE

The normal functions of the body make necessary a supply of protein to replace the daily break-down of the tissues of the body, as well as to provide for the growth of hair, horns, hoofs, and increase in body weight due to growth as well as fattening. Since protein-rich feeds are generally more expensive than carbohydrate feeds, it is important to know the minimum as well as the most effective amount of protein supplement required for maintenance and for fattening.

FOR MAINTENANCE

The minimum needs of cattle for protein for maintenance of life has been the subject of considerable research during the last 30 years. Two methods of approach to the problem of determining the minimum requirements for protein have been used. One is by means of the fasting catabolism, in which the protein required for maintenance is ascertained from the amount of nitrogen (protein) in the urine of fasting animals or animals on a nitrogen-free diet, that is, a diet without protein. The second method consists of determining the protein requirements from the best results of experimentation with cattle.

Brody (*157*), Mitchell (*795*), and others have attempted to ascertain the minimum requirements from the amount of what is called endogenous nitrogen secreted by the animal on a nitrogen-free but otherwise adequate diet. This endogenous nitrogen is assumed to be the nitrogen necessary for maintenance, since it represents the loss of nitrogen which must be made good by dietary protein in order to maintain the nitrogenous (protein) tissues of the body. Brody has suggested that the secretion of endogenous nitrogen follows the same relationship to weight of the animal as does the requirement for energy.[7]

Mitchell suggested that the protein requirements are proportional to weight. More recently Smuts (*1086*), working under Mitchell, has accepted the same relationship to weight that Brody suggests.[8] Brody has proposed that four times the urinary protein equivalent be used as a basis of maintenance, while Mitchell uses twice the urinary protein equivalent. In table 4 are shown the amounts of protein required for maintenance as proposed by Brody, by Mitchell, and by Morrison (*819*).

Morrison's standard is based on experimental evidence of the best results obtained with cattle. It is considerably above the standard proposed by Mitchell and in some cases above that of Brody. However, for wintering beef cows Morrison shows a little less protein required than does Brody for the same weight animal. Morrison states (*819*), with reference to the Mitchell standard:

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[7] It is believed that the surface area of an animal varies with the two-thirds to three-fourths power of its body weight and that basal metabolism varies with the surface area. From his data, Brody presented the following equation expressing endogenous nitrogen as a function of body weight: $N=146\,M^{0.72}$, in which N equals the milligrams of endogenous nitrogen per day and M equals the body weight in kilograms. By multiplying the nitrogen by a factor (6.25) the amount of conventional protein required for maintenance is obtained.

[8] Smuts proposed an equation for determination of protein requirements as follows: $P=0.88m^{0.734}$, where P is the daily requirement expressed in grams.

> Since it has not been proved by long-time feeding experiments that animals can actually be maintained in good health on this small amount of protein, the author has preferred not to recommend such small amounts in the feeding standards presented.

Table 4.—*Protein requirements for maintenance of beef and dual-purpose cattle as proposed by several investigators*

Live weight of animal (pounds)	Protein requirement per day, according to—		Minimum protein requirement per day, according to Morrison, for—			
	Brody	Mitchell	Dairy cattle	Beef calves	Yearling beef cattle	Cows
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
100	0.13	0.04				
200	22	08				
300	29	11		0.52		
400	.36	15		.63		
500	42	19		.71		
600	.48	.23		.79	0.67	
700	.54	.27	0.44		76	
800	.59	.30	49		83	
900	65	.34	55			0.56
1,000	70	38	.60			.60
1,100	.75	.42	.65			.64
1,200	.80	46	70			.69
1,300	.85	.49	.75			
1,400	89	.53	.80			
1,500	94	.57	85			
1,600	.99	61	.90			
1,700	1.03	.65	95			
1,800	1.07	68	1.00			
1,900	1.12	.72				
2,000	1.16	.76				

The amounts of protein given in table 4 are those required for wintering each class of beef cattle. It will be seen that the younger animals require more protein per unit of weight than do the older animals.

FOR GROWTH AND FATTENING

Differentiation of gain from growth and that from fattening is difficult, if not impossible, and for this reason they will be considered together. Growth may be considered as any increase in volume, or weight, of the animal, in which case fattening would be a form of growth. For purposes of differentiation, growth is defined in this discussion to mean increases in skeleton and the associated increase of muscular tissue, while fattening relates primarily to the increase in fatty deposits within the body due to the filling of certain tissues with fat. Fattening requires some increase in cellular material surrounding the fat and thus requires some protein. Likewise, an animal in the normal process of growth will fatten to some extent.

The Missouri Agricultural Experiment Station (*825*) has made a complete analysis of the carcasses of steers fed out on three planes of nutrition in order to ascertain the changes in composition due to growth and fattening. Group 1 was fed as much of the ration as they would consume. Group 2 was fed to produce the greatest growth without storage of surplus fat, and group 3 was fed to produce approximately half the rate of gain of the group 2 steers. A study of the change in the protein (nitrogen) content of these steers at various ages was obtainable from the analyses of the carcasses.[9] From these data, Mitchell has computed the necessary nitrogen for gains of the three groups. If it is assumed that these steers were fed as planned, some differentiation between growth and growth and maximum fattening might be made. In figure 3 is shown the necessary protein re-

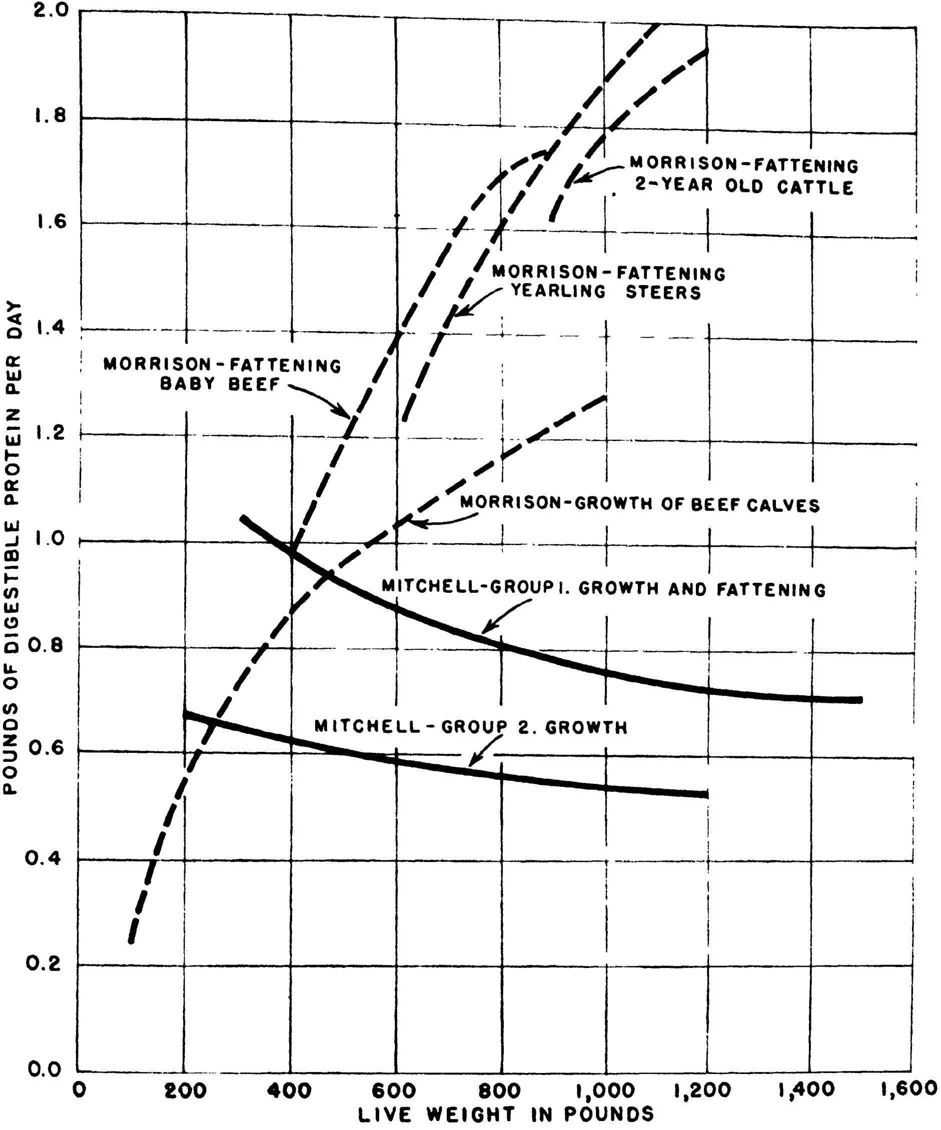

Figure 3.—Protein requirements for growth and fattening of beef cattle.

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[9] The changes in the nitrogen content were observed to follow the normal growth equation, $W=A-Be^{-kt}$, as proposed by Brody (*153*). The nitrogen changes were expressed for the three groups by the three equations (*825*): Group 1, $W=16.50-38.59^{-0.0729t}$; group 2, $W=16.25-25.59e^{-0.0449t}$; group 3, $W=15.50-18.23e^{-0.0246t}$, in which W is the total weight of nitrogen in kilograms and t is the age in months from conception. From these equations the rate of deposition of nitrogen for any age or for any weight for a given rate of feeding can be computed.

quired per day for groups 1 and 2, based on the daily retention of nitrogen (protein) obtained from the equations in footnote 9.

Morrison proposed a standard based on experimental evidence on the best results obtained in growing and fattening cattle. Except in the lighter weights, the Morrison standard is much higher than that proposed by Mitchell (fig. 3). It should be noted that where the Morrison standard requires an increasing amount of protein as weight increases, Mitchell shows a decreasing amount of protein required on the basis of daily retention. However, Morrison suggests less amounts per unit of weight for older cattle than for younger.

It would seem from the present status of knowledge of protein requirements of beef cattle that much careful investigation on this subject needs to be done. Since protein supplements are usually purchased at relatively high prices, it would be of considerable value to ascertain the most effective amount of protein required for maintaining, growing, or fattening beef cattle.

FOR REPRODUCTION

The protein or nitrogen requirement for gestation and lactation has been computed for cattle on the basis of the amounts of nitrogen in the fetus at various ages from conception, and in the case of lactation on the number of pounds of milk produced per day.

The additional requirements for the gestating female are not large, since the calf at birth weighs only about 70 to 80 pounds, of which approximately 71 percent is water. Mitchell (*795*) has proposed a standard based on the average changes in composition of cattle fetuses. The data do not contain the increase in maternal tissues, amniotic fluids, and other minor substances. From the data the information given in table 5 was available.

TABLE 5.—*Estimated daily protein requirement of cattle fetuses*

Age from conception (months)	Estimated daily retention of nitrogen	Estimated daily requirement of protein[1]
	Grams	*Pounds*
2	0.02	0.0005
3	.16	.0044
4	.61	.0168
5	1.6	.0442
6	3.3	.0911
7	5.9	.1628
8	9.9	.2732
9	10.0	.4416

[1] Computed on the basis of protein with a biological value of 50 percent.

It can be seen from table 5 that the daily retention is very low up to the last 3 months, when the fetus makes rather rapid growth. The highest requirement for protein—nearly half a pound—comes in the last month.

Since beef cattle do not produce large quantities of milk during lactation, the protein requirement for milk production is not high. Morrison recommends from 0.04 to 0.05 pound of additional protein for each pound of milk produced. Thus, a beef cow producing 10 pounds of 4-percent milk per day would require an additional 0.49 pound of digestible protein per day.

MINERAL REQUIREMENTS OF BEEF CATTLE

MINERALS IN THE ANIMAL BODY AND THEIR FUNCTIONS

That the animal body requires certain minerals is revealed through analyses of various species of animals. Such analyses were perhaps first made by Lawes and Gilbert (*665*) more than three-quarters of a century ago. To date, many animal bodies have been analyzed by scientists throughout the world. It is quite generally agreed as a result that the following minerals, which are always a part of body composition, are necessary to the perfect growth of the animal body and to the proper functioning of the organs: Calcium, phosphorus, sodium, potassium, chlorine, magnesium, iron, sulfur, iodine, manganese, copper, and zinc. It is the consensus of opinion that cobalt also is essential. Mitchell and McClure (*803*) state that a definite requirement for silicon, fluorine, bromine, aluminum, boron, or other minerals that occur in animal tissues or products has not been established. This might be done by the demonstration of nutritive failure in animals following the practically complete withdrawal of the individual element from rations complete in other respects; but only in the case of fluorine has such a test been made. There is the possibility that the presence in the body of these minerals, the functions of which are unknown, is attributable merely to their being in the feeds rather than to a need for them.

One of the most obvious functions of minerals in the animal body is their relation to skeletal structure (bones and teeth). They are also associated with organic compounds which contribute to the functional activities of the body. The percentage composition of a steer has been reported by Hogan and Nierman (*527*), who express the results in terms of the fat-free body. (This is desirable because fat is low in minerals and is a variable constituent of the animal body.) The composition is as follows: Water, 75 percent; protein. 20 percent; and mineral matter, 5 percent. The average of analyses of 18 steers of varying ages (3 to 48 months) shows the principal mineral constituents of the body to be present in approximately the following proportions:

	Percent		*Percent*		*Percent*
Calcium	1. 33	Sodium	0. 16	Magnesium	0. 041
Phosphorus	. 74	Sulfur	. 15	Iron	. 013
Potassium	. 19	Chlorine	. 11		

These investigations do not indicate that the mineral content of the lean and fat, or of the hide and hair, is affected by age or condition. There is, however, a distinct tendency for the percentages of all the mineral elements in the internal organs to decrease with age. Most of the mineral constituents of the blood are not affected by age, except that sodium tends to decrease in the blood of older animals. Calcium, phosphorus, and magnesium in the skeleton increase in percentage with age.

All of these elements are considered essential to life and will be discussed briefly later, but the major part of the discussion will be devoted to calcium and phosphorus, since they are the ones most likely to be lacking in the diet. Approximately 90 percent of the ash or mineral matter resulting from the combustion or burning of an animal body consists of calcium and phosphorus, and about 99 percent of the calcium and 80 percent of the phosphorus are in the bones and teeth. There is a very close relationship between these elements with respect to their functions in the animal body, and an interrelationship likewise between their utilization and vitamin D.

The satisfactory ratio of calcium to phosphorus in a ration seems to be between 2:1 and 1:2. With plenty of vitamin D the ratio becomes of less importance, and more efficient utilization is made of the amounts of the elements present. In the entire absence of this vitamin, assimilation is poor even though the other factors are optimum.

Experiments by Theiler, Green, and Du Toit (*1130*) showed that for growth minimal requirements for phosphorus are higher than those for calcium, and that a ratio of calcium to phosphorus of approximately one to two is not necessarily disadvantageous.

The inorganic phosphorus content of the blood is a useful measure of adequate or inadequate phosphorous nutrition. The inorganic phosphorus content of blood from animals receiving sufficient phosphorus varies from 4 to 9 milligrams per 100 cubic centimeters of blood, depending on the age and species of the animal; the younger the animal, generally speaking, the higher the inorganic phosphorus content. In phosphorus deficiency the inorganic phosphorus content of the blood decreases. The method reported by Malan and Van Der Lingen (*743*), of South Africa, for determining the inorganic phosphorus and other mineral contents of blood from livestock and the detection of mineral deficiences through such analyses has contributed much to the livestock industry of South Africa. Similar methods are being used rather extensively by scientists in the United States and other countries for locating areas of mineral-deficient soils and the extent of the deficiencies.

THE NATURE OF MINERAL DEFICIENCIES

A continued deficiency of phosphorus in the ration leads to a condition called aphosphorosis, which was identified in 1924 by Theiler, Green, and Du Toit (*1129*). The first symptoms of a phosphorus deficiency are usually manifested by a perverted or depraved appetite (pica) on the part of the animal as evidenced by the chewing of wood, bones (osteophagia), dirt, and other miscellaneous material. When the disease advances to the stage where development of the bodies of affected cattle is materially impaired, it is known by such names as "styfsiekte" in South Africa (*435*), "stiffs" or "sweeney" in Florida (*83*), and "creeps" in Texas (*1015*).

The appetite of cattle in advanced stages of phosphorus deficiency becomes so depraved that even rotten bones are eaten, and when this material is infected with germs or organisms called *Clostridium botulinum*, a disease called lamsiekte in South Africa develops and usually proves fatal. This condition is probably identical with that known as loin disease, which is seen in cattle in certain parts of the United States.

Calcium and magnesium deficiencies, like phosphorus deficiency, affect the skeletal structures and the function of reproduction. Theiler (*1126, 1127*) has given the name "acalcicosis" to calcium undernutrition. It is likely, however, except in special cases, that magnesium and calcium deficiencies are not sufficiently serious in any section of the United States to have any material effect on mature beef cattle.

Rickets is a nutritional disease closely related to a deficiency of phosphorus, calcium, or vitamin D, particularly in young animals. Rickets may develop with a sufficient supply of phosphorus and calcium or an abnormal ratio of calcium and phosphorus in the diet when there is a lack of sufficient vitamin D, the antirachitic vitamin which greatly influences the metabolism of calcium and phosphorus and bone formation.

Chlorine is required by animals since it is a constituent part of body tissues and fluids and is used in many functions such as the formation of hydrochloric acid, which aids in certain phases of the digestion.

Iodine deficiencies are quite common in the Northwest and the upper Mississippi Valley, and usually show in the form of goiter and weakness in newborn calves, lambs, foals, and kids, and hairlessness and goiter in newborn pigs.

Iron deficiency produces anemia, which can readily be determined in the laboratory by the determination of hemoglobin, the red coloring matter of blood, or by counting the number of red blood cells per unit volume with the aid of a microscope.

Cobalt, according to Marston, Lines, Marshall, and Hosking (*756*), is useful in correcting a specific nutritional deficiency disease in sheep in Australia, called coast disease, which is characterized by a severe anemia. Neal and Ahmann (*835*) of the Florida Agricultural Experiment Station report an experiment in which calves were fed cobalt, with and without supplementation of iron and copper, in conjunction with a basal ration consisting of Natal grass hay, shelled corn, and skim-milk powder. The hay and corn were produced on cobalt-deficient land. The authors report that—

> the results of these trials indicate very clearly the beneficial effect of a cobalt supplement to the basal ration; and the deleterious effect of ferric ammonium citrate and copper sulfate. A malnutrition has been produced in calves that is prevented or cured by cobalt supplementation and is aggravated by the use of iron and copper supplement.

The value of minerals in correcting a specific mineral deficiency depends upon the absorption, which in turn is affected to a great extent by the solubility of the particular compound fed and its ratio to other minerals present.

MINERAL CONTENTS OF FEEDS

By knowing the mineral contents of feeds and the approximate mineral requirements of animals it is possible in most instances to prevent or correct mineral deficiencies by proper supplementary feeding if the deficiency has not progressed to the point of permanently injuring the animals.

Certain groups of feeds are high in calcium content and others are high in phosphorus. For instance, the legumes (alfalfa, clover, lespedeza, etc.), milk products, and fish meal are rich in calcium; and the wheat and rice products (bran, middlings, red-dog flour, and rice polish), legume seeds, protein meals (cottonseed and linseed), and milk and animal products (meat meal, tankage, fish meal, etc.) are phosphorus-rich feeds.

The mineral contents of some of the more common cattle feeds are given in table 6. In reviewing this table it may be noted that alfalfa hay contains approximately four times as much calcium as timothy hay, and that fish meal contains about six times as much calcium as alfalfa. Nevertheless, alfalfa is considered a good source of calcium, and owing to its relative availability, it is a more popular source than fish meal. Rice polish contains more than four times as much phosphorus as timothy hay. Yet, even though timothy hay is low in calcium, limited experimental work has shown no bad effect on milk production or growth when it is fed to dairy cattle as the chief source of calcium.

Table 6.—*Mineral content of some feeds, in percentage of substance as fed* [1]

Feed	Dry matter	Calcium	Phosphorus	Potassium	Magnesium	Sodium	Chlorine	Sulfur
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Seeds:								
Barley	90.0	0.07	0.32	0.51	0.16	------	------	0.14
Corn	86.9	.01	.26	.32	.11	0.02	0.04	.13
Oats	91.1	.10	.39	.42	.12	.17	.07	.20
Wheat	87.7	.05	.37	.52	.13	.03	.08	.20
Seed byproducts:								
Brewers' grains	93.1	.16	.47	.17	.16	.26	.06	.39
Corn-gluten feed	94.3	.11	.81	1.06	.40	.97	.21	.71
Cottonseed meal	92.8	.19	1.11	1.46	.59	.04	.03	.41
Distillers' grains, corn	92.3	.04	.29	.01	.05	.14	.06	.47
Distillers' grains, rye	91.7	.13	.42	.04	.18	.07	.03	.37
Linseed meal	91.1	.36	.84	1.25	.53	.10	.40	.39
Red-dog flour	89.5	.12	.83	38	.29	.66	.14	.26
Rice polish	88.9	.03	1.50	1.14	.66	.11	.13	.17
Wheat bran	91.0	.10	1.15	1.12	.51	.04	.03	.20
Wheat middlings	88.5	.09	.89	.90	.34	.10	.03	.21
Forage crops, green:								
Alfalfa	19.0	.42	.05	.77	.04	.05	.12	.11
Bluegrass	25.0	.08	.06	.35	.06	.04	.06	.08
Clover, red	20.0	.36	.05	.92	.07	.06	.13	.08
Corn, silage	27.0	.03	.06	.26	.08	.01	.05	.04
Oats	12.0	.06	.05	.83	.02	.07	.19	.05
Rye	12.0	.06	.06	.84	.01	.04	.22	.08
Dry roughages:								
Alfalfa	90.4	1.47	.20	1.32	.27	.09	.20	.26
Clover, red	88.4	.96	.13	1.62	.25	.03	.05	.12
Corn stover	93.0	.47	.10	1.72	.09	.06	.29	.17
Cowpea	89.1	1.82	.25	.78	.98	.65	.15	.32
Soybean	89.4	1.23	.21	1.58	.62	.13	.08	.23
Straw, oat	91.1	.23	.20	1.29	.16	------	------	------
Straw, wheat	94.5	.20	.04	.80	.06	.22	.20	.15
Timothy	91.0	.38	.18	1.24	.12	.06	.27	.06
Roots and tubers:								
Beet pulp	90.5	.66	.06	.31	.25	.17	.04	.13
Mangel-wurzels	11.5	.02	.03	.44	.04	.08	.16	.03
Turnips	9.4	.05	.05	.26	.01	.03	.05	.04
Animal products:								
Bonemeal, steamed	96.8	30.00	13.90	.13	.78	.47	.06	.31
Fish meal	92.7	9.09	4.70	------	------	------	------	------
Meat meal	90.5	1.21	.89	1.15	.13	.44	.86	.32
Skim milk	9.6	.13	.09	.24	.01	.05	.09	.03
Tankage	90.0	2.95	1.63	.55	.15	1.66	2.44	.61

[1] Data from Ohio Agricultural Experiment Station Bulletin 255 (*871, pp. 225-227*), National Research Council Bulletin 99 (*803*), and results of analyses made in the laboratories of the Bureau of Animal Industry.

In many sections of the United States, particularly in the West in areas where beef cattle subsist almost entirely on the range, it is more practical and perhaps less expensive in the majority of cases to supply phosphorus, and perhaps other minerals, from sources other than grains and forage crops. Limestone, bonemeal, spent bone black, and oystershell are good sources of calcium. Bonemeal, spent bone black, and dicalcium and disodium phosphates are good sources of phosphorus. The chemical salts, such as dicalcium phosphate, as a rule are not palatable and cattle will not eat them unless they are mixed with common salt or with some palatable feed or dissolved in the drinking water. Superphosphate, dicalcium phosphate, or ground rock phosphate may be used as a source of phosphorus, but great caution must be exercised to be sure the product is low in fluorine. A chemical analysis should be made to see that there is not more than 0.10 percent of fluorine or of arsenic present.

The minerals most likely to be needed to supplement feeds are common salt, calcium, phosphorus, and in some cases iodine and iron. The need in some instances for the addition of other minerals has been recognized, but the quantities required have not been adequately demonstrated.

To a large extent, the judicious selection of feeds for purposes of providing supplemental proteins and vitamins as well as increased palatability will balance the ration with respect to minerals also. Mineral-deficiency problems are frequently local, being due to deficiencies in the soils producing the livestock feeds. A particular element may become a limiting factor to successful nutrition. Thus, a calcium or phosphorus deficiency leads to arrested or distorted bone development in young animals, an iodine deficiency to goiter, and iron deficiency to nutritional anemia, to mention the more common examples.

Rations consisting largely of the cereal grains are relatively rich in phosphorus, but require the addition of calcium-rich supplements, such as the legume hays, limestone, or a combination of limestone and bonemeal, to provide a more favorable ratio of calcium to phosphorus. When protein supplements of such rations consist of tankage containing considerable bonemeal, fish meal, or milk, the need for mineral supplements is not so great. Nonleguminous pasturage sometimes may be supplemented by the addition of bonemeal or a mixture of equal parts of limestone, bonemeal, and salt. In certain regions the phosphorus content of grass or hay is low, and in such cases bonemeal, linseed meal, cottonseed meal, or some other phosphorus-rich feed can be supplied to balance the ration.

CALCIUM AND PHOSPHORUS REQUIREMENTS

The requirements of animals for calcium and phosphorus must be satisfied from feeds which may vary considerably in their content of these minerals. Accordingly, it is advisable to provide a margin of safety in feeding standards, based as they must be on average requirements and contents. When legume hays—alfalfa, clover, or soybean—are liberally fed, little or no mineral addition is required.

Table 7 shows the approximate calcium and phosphorus requirements of growing, fattening, pregnant, and lactating beef cattle. It will be noted that the calcium and phosphorus requirements are greater for growing and breeding than for fattening cattle.

Generally speaking, any feed mixture or mineral mixture that will supply 10 to 15 grams of P_2O_5 (phosphorus pentoxide) or its equivalent, 4 to 6.5 grams of phosphorus, per head daily should prevent a phosphorus deficiency in cattle grazing on phosphorus-deficient range,

TABLE 7.—*Approximate calcium and phosphorus requirements of beef cattle, in percentages of the dry ration, and suggested types of feeds which, when fed in accordance with good practice, are usually capable of meeting the requirements*

Period of development of cattle	Approximate calcium requirement	Feeds providing calcium to meet requirements or balance the ration	Approximate phosphorus requirement	Feeds providing phosphorus to meet requirements or balance the ration
	Percent		*Percent*	
Growing (400 pounds).	0. 4	Legume forage	0. 3	Forage above average in phosphorus or grains with cottonseed meal or wheat bran.
Fattening (900 pounds).	. 2	Mixed grasses or hays	. 2	Usual grain ration adequate.
Pregnant (late)	. 4	Liberal ration high in legume forage.	. 3	Liberal ration including grain.
Lactating	. 3	Legume forage as part of roughage, or bonemeal in grain ration	. 25	Addition of concentrates such as wheat bran, linseed meal, cottonseed meal.

and possibly correct an existing deficiency if the disease has not reached advanced stages.

In South Africa where mineral metabolism of cattle has been one of the foremost nutritional problems for investigation for many years, Du Toit and Bisschop (*287*) obtained significant results from the feeding of bonemeal to breeding cows grazing on phosphorus-deficient veld. In the experiment the cows and heifers in calf and lactating cows were fed 5 ounces of bonemeal daily (except Sundays) and all growing and dry stock 3 ounces. The calves were fed the bonemeal supplement from weaning at 9 months of age until 30 months old. The results of this experiment were outstanding and are no doubt applicable to many of our range production areas, especially in the South and Southwest. Over a 3-year period bonemeal-fed cows had produced an average calf crop of 87.3 percent as compared to 56.3 percent for the controls. In the bonemeal group 66.1 percent had 3 calves in 3 years, while not a single cow among the controls produced a calf each year.

The feeding of bonemeal hastened sexual maturity and favored breeding regularity. Of the bonemeal-fed heifers, 84.4 percent became pregnant when turned with the bull at from 2 to 2¼ years of age, whereas only 73.7 percent of the control heifers became pregnant. The average birth weights of the two groups were 68.8 and 68.1 pounds respectively for the bonemeal and control calves; but at weaning time (about 9 months) the calves from the bonemeal-fed cows weighed 16.5 percent more, and at 30 months of age, 243 pounds or one-third more. The feeding of bonemeal significantly increased the milk flow of the cows, and this in turn favored increased growth and skeletal development of the calves. A study of skeletal development made through a series of body measurements showed a marked superiority of the bonemeal-fed calves in nearly every measurement taken.

Hart and Guilbert (*495*) increased the calf crop by supplementing range pastures in California with bonemeal. Schmidt (*1015*) found that "creeps" could be prevented and bone chewing stopped in about 75 percent of the cases studied in the Gulf coast section of Texas.

Beeson and Hickman (*85*) found that a ration containing 0.12 percent of phosphorus and supplying 8.23 grams daily to growing calves in Idaho resulted in poor condition of calves, rough coat of hair, and chewing of wood and eating of dirt by the calves. Their results indicated that 2 grams of phosphorus for each 100 pounds of live weight would meet the requirements of growing calves.

The South African investigators, Malan, Green, and Du Toit (*742*), found that heifers on phosphorus-deficient pasture fed bonemeal from 9 months to 2 years of age maintained a normal content of 5 milligrams of inorganic phosphorus per 100 cubic centimeters of blood, whereas control heifers showed only half that amount.

Bekker (*86*) in South Africa reports experiments showing two-thirds of an ounce of dicalcium phosphate to be as effective as 3 ounces of bonemeal or 1½ ounces of disodium phosphate. In choosing between these sources it should be taken into consideration that bonemeal is palatable to cattle and no trouble is experienced in getting them to eat it, whereas dicalcium phosphate and disodium phosphate are seemingly not palatable when fed alone. The former is only slightly soluble in water and accordingly must be hand-dosed or mixed with salt or a palatable feed. Disodium phosphate is soluble in water and can be placed in the drinking water, but this can be done satisfactorily only when the cattle are compelled to get their water from a supply treated with the salt. The South African investigators reported that when disodium phosphate (20-percent phosphorus pentoxide) was dissolved in the water supply at the rate of 45 grams per 6 gallons of water, the cattle drank 5.8 gallons of water each, and thus obtained 1.56 ounces of phosphorus pentoxide daily, or 0.68 ounce of phosphorus.

The so-called deficiency diseases—loin disease, creeps, salt sick, stiff, hill sick, etc.—appearing in range-cattle herds, particularly in the South and Southwest, are being investigated in view of the excellent results obtained in South Africa in the feeding of phosphorus to range cattle. The Department of Agriculture and the Texas Agricultural Experiment Station are carrying on an experiment in cooperation with the King Ranch in south Texas to determine satisfactory methods of correcting phosphorus deficiencies in cattle on the range. A general survey covering several months and extending quite generally over southern Texas indicated through the chemical analyses of hundreds of forage samples and of several soils that a phosphorus deficiency of considerable consequence exists in many sections of the Texas Gulf coast country. The chemical analyses did not reveal a calcium deficiency of importance.

The administration of mineral supplements to cattle in this experiment (fig. 4) was begun in January 1937. Four groups of 25 head each of yearling heifers were random-selected and are being handled as follows:

Group 1: Controls (no supplement).

Group 2: Fed approximately 3 ounces of bonemeal per head daily (Sundays excepted).

Group 3: Fed approximately 1½ ounces of disodium phosphate per head daily.

Group 4: Fed approximately 3 ounces of bonemeal and 160 milligrams of iron supplied in the form of ferric ammonium sulfate, 100 milligrams of manganese as manganese sulfate, 15 milligrams of copper as copper sulfate, 15 milligrams of

Figure 4.—An experiment to determine satisfactory methods of correcting phosphorus deficiency in range beef cattle. Different groups of animals are given different mineral supplements daily. Results will be checked against a group that receives no supplement.

zinc as zinc sulfate, 15 milligrams of cobalt as cobalt sulfate, and 15 milligrams of boron as sodium tetraborate (borax) per head daily (Sundays excepted).

All groups, including the controls, are handled through the corrals and chute so as to reduce any variable in handling to a minimum. The heifers in the mineral-fed group are individually hand-dosed. Blood samples are taken every 14 days from five heifers in each group, so that the blood from each animal is sampled every 70 days. When this part of the experiment had been under way for only half a year, there had been a marked response to the feeding of the mineral supplements, as evidenced by the appearance and gains of the cattle, which were checked every 28 days. The analyses of the blood samples also showed a marked improvement in the inorganic phosphorus content of the blood in the groups fed mineral supplements over the control group.

It is planned to conduct this experiment over a period of several years, taking at regular intervals weights and measurements of the calves produced, for growth and skeletal-development studies. The effect of feeding minerals or mineral supplements on percentage calf crop, sexual maturity, and milk or beef production or both will be studied. In this experiment the mineral supplements are fed so as to supply 15 grams of phosphorus pentoxide per head daily in addition to that in the pasturage. It is estimated that this quantity will not only meet the phosphorus requirement but leave a margin for safety. Plans call for following this experiment with one in which

TABLE 8.—*Estimated daily calcium and phosphorus requirements of growing and fattening beef steers*

GROWING STEERS

Body weight (pounds)	Dry matter requirement[1]	Net requirement of calcium	Feed calcium required	Necessary percentage of calcium in ration	Net phosphorus requirement	Feed phosphorus required	Necessary percentage of phosphorus in ration
	Grams	*Grams*	*Grams*	*Percent*	*Grams*	*Grams*	*Percent*
300	3, 552	10. 6	15. 1	0. 43	8. 6	12. 3	0. 35
400	3, 993	9. 9	14. 1	. 35	8. 7	12. 4	. 31
500	4, 541	9. 3	13. 1	. 29	8. 7	12. 4	. 27
600	4, 861	8. 6	12. 3	. 25	8. 7	12. 4	. 26
700	5, 291	7. 9	11. 3	. 21	8. 6	12. 3	. 23
800	5, 644	7. 3	10. 4	. 18	8. 5	12. 1	. 21
900	5, 971	6. 7	9. 6	. 16	8. 4	12. 0	. 20
1,000	6, 400	6. 2	8. 9	. 14	8. 4	12. 0	. 19
1,100	6, 783	5. 7	8. 1	. 12	8. 4	12. 0	. 18
1,200	7, 154	5. 3	7. 6	. 11	8. 3	11. 9	. 17
FATTENING STEERS							
300	5, 198	17. 3	24. 7	0. 48	12. 5	17. 9	0. 34
400	5, 602	15. 8	22. 6	. 40	12. 2	17. 4	. 31
500	6, 190	14. 5	20. 7	33	11. 7	16. 7	. 27
600	6, 501	13. 4	19. 1	. 29	11. 5	16. 4	. 25
700	6, 974	12. 4	17. 7	. 25	11. 2	16. 0	. 23
800	7, 348	11. 5	16. 4	. 22	10. 9	15. 6	. 21
900	7, 683	10. 6	15. 1	. 20	10. 7	15. 3	. 20
1,000	8, 157	9. 8	14. 0	17	10. 5	15. 0	. 18
1,100	8, 568	9. 1	13. 0	. 15	10. 4	14. 9	. 17
1,200	8, 966	8. 4	12. 0	. 13	10. 2	14. 6	. 16

[1] In computing the dry matter requirements, the ratios of dry matter to total digestible nutrients required are the same at different body weights as those recommended in the Morrison standards (*819*).

phosphorus will be fed at different levels, so as to determine a more accurate measure of the minimum requirements.

Until further experimental evidence is available on mineral requirements of beef cattle, it may be the best plan, with few exceptions, to consider calcium and phosphorus as the minerals which have a real economic relationship to the cattle industry. In this connection the estimated daily requirements for growing and fattening beef steers, as reported by Mitchell and McClure (*803*) and presented in table 8, may be considered as a very good guide.

VITAMIN REQUIREMENTS OF BEEF CATTLE

Since the first vitamin was discovered some 25 years ago, knowledge in this field has steadily expanded, largely through the medium of laboratory experimentation with rats, guinea pigs, pigeons, and chickens. At present, according to Maynard (*769*), there are at least eight vitamins for the existence of which there is definite evidence. That others undoubtedly exist should not be overlooked, though current evidence is somewhat conflicting and entirely too fragmentary to warrant any definite conclusions.

Present knowledge with reference to the daily requirements of these dietary essentials in the feeding of beef cattle is extremely meager. It is known, however, that of the vitamins found to be essential for the well-being of beef cattle, relatively minute quantities are required to meet the daily needs. In the absence of these minute quantities, however, serious complications will develop, so that the feeding of nutrients containing sufficient amounts of the essential vitamins is necessary to insure health and well-being of the cattle.

VITAMIN A

Vitamin A, a fat-soluble vitamin, was identified by McCollum and Davis (*723*) and Osborne and Mendel (*881*). Animals are able to form vitamin A in their bodies from certain yellow pigments known as carotinoids, which are found in most plants. Vitamin A may also be supplied in fish oils. Results of experiments in feeding cattle in which such feeds as cottonseed meal, cottonseed hulls, and white hagari, or poor quality roughages are used, show clearly the need of this vitamin.

It is generally agreed that animals fed rations deficient in vitamin A are usually more susceptible to specific infections, notably those of the respiratory tract, than are animals receiving an ample supply of this vitamin. There appears to be some difference of opinion among investigators as to whether animals receiving vitamin A in excess of that necessary to overcome deficiency symptoms have any increased resistance to infectious diseases. One of the major functions of this vitamin appears to be to maintain the epithelium, or lining, of the mucous membranes of the body in a healthy state and thus retard or prevent bacterial invasion (*1247*).

An early symptom of vitamin A deficiency in cattle, commonly referred to as night blindness, is characterized by an inability of the animal to see in a dim light. If this condition is not alleviated complete blindness may follow. As the deficiency continues, a general degeneration of the nerves controlling vision and the coordination of the extremities develops. This condition has been observed in other animals as well as in cattle (*558*, *1111*), and spasms, paralysis, and death often result.

Hart and Guilbert (*496*) have shown that cattle develop symptoms of vitamin A deficiency when grazed on ranges which, after an extended dry period, have become almost devoid of carotene. Cows on such ranges usually fail to breed regularly or they may abort at varying intervals after conception. Calves that survive are usually weak, frequently scour, and are very susceptible to respiratory diseases such as pneumonia. Animals that have not been too seriously depleted of vitamin A usually recover when given access to feed rich in carotene or vitamin A.

Because of the inconsistency between methods used by different investigators to detect quantitatively early clinical symptoms of vitamin A deficiency, a more desirable method has been sought. Moore (*806*) has suggested two methods. The first consists of following the level of blood carotene. In this test the proteins in the blood plasma are precipitated by the use of alcohol, and the yellow pigments soluble in petroleum ether are extracted. The concentration of the yellow color is taken as an index of the amount of carotene present. This is measured by the use of a Lovibond tintometer. Below certain levels reproductive difficulties and vitamin A deficiencies occur. The second method involves the observation of the head of the optic nerve of the eye by the use of an ophthalmoscope. When vitamin A deficiency exists changes described as papillary edema and clouding of the disk are observed. By the use of these two guides vitamin A deficiency can be diagnosed long before the health of the animal is so impaired as to make proper recovery impossible.

In feeding tests at Spur, Tex., cooperatively conducted during 1934–35 by the Bureau of Animal Industry and the Texas Agricultural Experiment Station (data unpublished), steer calves were fed different amounts of alfalfa hay to furnish carotene in rations largely composed of cottonseed meal and cottonseed hulls in order to establish a practical level of alfalfa feeding for the prevention of vitamin A deficiency in growing and fattening steers. Steers fed 1, 2.5, and 5 pounds daily of alfalfa hay showed no indication of the deficiency, while steers receiving a ration composed of cottonseed hulls, cottonseed meal, and white kafir chops exhibited symptoms of vitamin A deficiency after having been on the ration for 140 days. One group of five steers was fed 1 pound daily of alfalfa hay in addition to the meal and hulls for 500 days. These steers made an average daily gain of 1.6 pounds and there was no appreciable manifestation of vitamin A deficiency among them. In subsequent experiments yearling steers, depleted of bodily stores of vitamin A and carotene by a ration composed of 12 percent of cottonseed meal and 88 percent of cottonseed hulls and fed a supplement of carotene from alfalfa at levels of 200, 350, and 500 micrograms per 100 pounds of body weight daily, gave indication that these levels were insufficient for normal health and growth. Another group of steers fed carotene at a level of 750 micrograms daily fared better than the three last-mentioned groups, but did not exhibit the alertness and activity of the fifth group, fed 2,400 micrograms of carotene daily per 100 pounds of live weight.

In later experiments conducted on a narrower range of carotene levels, 40 steer calves were depleted of vitamin A storage on a ration composed of 3 percent of tankage, 10 percent of cottonseed meal, and 87 percent of cottonseed hulls. As this group became depleted they were placed on fattening rations furnishing from 450 to 1,000 micrograms of carotene per 100 pounds of live weight daily through the medium of alfalfa meal. Another group of 10 steer calves was fed a ration similar to that for the depletion group and in addition received 800 micrograms of carotene per 100 pounds of live weight daily, which was supplied in alfalfa meal. Night blindness first appeared at 101 days in the groups fed the depletion ration. The average length of time, however, was 136 days, with 65 percent of the cattle showing symptoms between 125 and 160 days. Two steers withstood the effects of the depletion ration for 206 days. Symptoms in addition to night blindness included excessive discharge from the nose and eyes, slobbering, swelling of the joints, loss in weight, unsteady gait, and convulsions.

Feeding at a level of 450 micrograms of carotene produced complete night blindness in all steers on this ration. At levels of 600 and 750 micrograms convulsions and sickness were prevalent and complete night blindness occurred in the majority of cases. When the carotene content was raised from 750 to 1,250 micrograms, this group of steers showed slight improvement at the end of 3 weeks. Night blindness occurred in every case in which a level of 800 micrograms was fed from the beginning of the experiment, but the time required to produce this condition in the calves of this group was greater than that for calves fed depletion rations from the outset. Normal vision was restored rapidly when the number of micrograms of carotene from alfalfa was increased to 2,000, or when an equivalent amount of vitamin A was furnished in cod-liver oil. The group receiving 1,000 micrograms of carotene did not improve in night vision when fed at this level for 120 days. In fact, the steers slowly approached complete blindness. The variation in the rate of gain of the steers on different carotene levels was not significant.

In still later experiments at Spur (1937–38), 50 steer calves were placed on the vitamin A-depletion ration. When the first 35 showed symptoms of vitamin A deficiency, they were divided into 5 groups and placed on a basal fattening ration consisting of 3 percent of digester tankage, 15 percent of cottonseed meal, 30 percent of ground white corn, and 52 percent of cottonseed hulls, with alfalfa meal in addition at carotene levels of 800, 1,000, 1,250, 1,500, and 2,000 micrograms daily per 100 pounds of live weight, respectively. The remaining 15 were handled in similar fashion when they became depleted. After carotene was fed for 84 days it was evident that 800 micrograms per 100 pounds of live weight daily was not sufficient to control night blindness. The cattle on levels of 1,000 and 1,250 micrograms of carotene approached total night blindness, but appeared to be more active than the previous group. The groups receiving 1,500 and 2,000 micrograms showed the same average degree of night blindness but were markedly more alert and active than the 800- and 1,000-microgram groups. The 2,000-microgram group appeared to regain normal night vision entirely for a period of about 10 to 14 days after starting on that level, but for the 4 weeks following they exhibited gradually increasing night blindness.

Guilbert and Hart (*444*) report that lactation is probably a greater strain on the reserve supply of vitamin A than is gestation. They also state that the vitamin A reserve appears to be low for young growing animals but that it increases with age if the animals have access to feeds containing sufficient amounts of carotene. Maximum storage was found in the adult of advanced age.

According to the work of Converse and Meigs (*220*), cows should receive, for normal calving, from 80 to 100 milligrams of carotene daily during the last months of gestation. A daily intake of only 60 milligrams is liable to result in an appreciable number of dead calves. Although these results pertain to dairy cows, the data may be applicable to beef and dual-purpose cows in similar stages of gestation.

Ward and others (*1181*), in an effort to determine the carotene requirements of growing calves, fed 27 dairy calves 1,200 to 1,400 micrograms of carotene per 100 pounds of body weight without producing symptoms of vitamin A deficiency. Increasing the dosage 200 to 300 micrograms did not appear advantageous.

In determining the minimum vitamin A requirements of beef cattle ranging in age from 7 months to 4 years, Guilbert and Hart (*445*) added carotene to deficient rations in the form of chopped alfalfa hay or dehydrated alfalfa meal of known carotene content. The dose was increased periodically until the amounts ingested were sufficient for normal weight increase and to alleviate all clinical symptoms of deficiency. Recovery experiments were inaugurated when the animals exhibited complete blindness in semidarkness. The carotene level at which night blindness disappeared permitted gains up to 2.86 pounds daily. These workers concluded that from 26 to 33 micrograms per kilogram (2.2 pounds) of live weight were needed for minimum requirements. In most instances, symptoms reoccurred when the intake of carotene fell below 29 micrograms, but this level prevented or cured clinical symptoms of deficiency. This minimum requirement in micrograms per 100 pounds of live weight ranges from 1,200 to 1,500. These investigators suggest that the carotene or vitamin A requirement of cattle and other animals is directly related to body weight rather than to energy requirement.

Semb and his associates (*1026*) found the vitamin A and carotene content of butterfat prepared from colostrum to be 5 to 15 times as great as that of ordinary butterfat. Vitamin A and carotene were found in largest quantities in the milk immediately after freshening and appeared to drop rapidly the first week, with a continued but more gradual decrease in the subsequent weeks. Calves should be allowed to obtain colostrum whenever possible, since it serves as an important source of vitamin A as well as other factors.

Halverson and Sherwood (*461*) concluded that failure of cows on rations of peanut meal, linseed meal, or soybean meal with a mineral mixture and a poor roughage was due primarily to a vitamin A deficiency, and that symptoms of "cottonseed meal poisoning" were not due to the presence of a toxic substance in the meal.

VITAMIN B COMPLEX

Experimental work has shown that the antineuritic vitamin B_1 (thiamin) is required by man, dogs, poultry, pigeons, rats, mice, and possibly swine. In experimental work with cattle, Bechdel and others (*75*) fed rations to cattle insufficient in what was then (1926) known as vitamin B with no ill effects. Their work indicates that calves will grow normally to maturity and will produce normal offspring on a ration that contains an insufficient amount of vitamin B (old nomenclature) to support growth and general well-being in the rat. However, successful lactation was never obtained for more than several weeks.

Bechdel concluded that either the calf has a very low requirement compared to the rat, or that the vitamin is produced by synthetic action in the digestive tract. It has been shown that certain bacteria possess this synthesizing power. There can be little doubt that Bechdel and associates fed appreciable quantities of some vitamin B factors in their experiments, since crude commercial casein was included in their experimental rations. At present, there is no information available regarding the need of cattle and other large farm animals for the individual vitamins known to make up the vitamin B complex. Eckles and Williams (*301*) studied the effect of yeast as a supplemental feed in rations for lactating cows and obtained negative results. However, Newman and Savage (*852*) recently reported that the use of dried brewers' yeast and cereal yeast feed in dry calf-starter formulas fed to calves which received a limited amount of milk resulted in greater growth and body development than was obtained without these supplements.

OTHER VITAMINS

So far as is known today, the antiscorbutic vitamin (vitamin C or ascorbic acid) is required only by man, monkey, and guinea pig. The relatively few experiments which have been conducted have failed to disclose any need for this vitamin in the diet of cattle (*1136*). Phillips and associates (*921*) report that vitamin A or its precursors is concerned directly or indirectly with the maintenance of vitamin C levels in the blood plasma and urine of calves when they are maintained on a certain experimental ration primarily deficient in vitamin A. These workers submit additional evidence that cattle require a dietary factor necessary for normal blood clotting that is believed to be vitamin K.

It has been shown that beef cattle must have an adequate supply of vitamin D to enable them efficiently to assimilate and utilize the calcium and phosphorus in their feed and to prevent the development of rickets. There are no experimental data available as to the requirements for this vitamin for growth, fattening, and reproduction of beef cattle. Bechdel and his associates (*76*) state:

> The minimum level of vitamin D for growth, well being, and proper calcification of bones of calves from birth to 7 months of age as found under the conditions of this experiment, is approximately 300 U. S. P. units per day per 100 pounds live weight.

Vitamin D supplement was fed in the form of irradiated yeast, oxidized cod-liver oil, and unaltered cod-liver oil. Long, Huffman, and Duncan (*696*) state:

> When winter and early spring whole milk furnished the only source of vitamin D, the daily intake of 0.3 to 0.4 U. S. P. units per pound of body weight appeared to meet the requirement of the growing calf, when normal plasma magnesium values were maintained.

This may suggest a more efficient utilization of vitamin D by the calf from natural vitamin D in milk than from other sources.

Vitamin E is of significance in the nutrition of some other species of animals, but experiments planned to demonstrate the importance of or the requirements for this vitamin in the feeding of cattle have not been satisfactorily confirmed. Vitamin E is necessary for reproduction in the rat, according to Evans (*342*), and there is evidence that this vitamin is essential for normal reproduction in poultry also. Thomas and Cannon (*1133*) have shown that goats may reproduce without unusual difficulty on rations devoid of vitamin E; in fact, they report an original herd of 7 goats to have increased to 48 on rations treated to destroy vitamin E.

From this review it is plain that the vitamin requirements of beef cattle and other farm animals, with the possible exception of poultry, are little known and therefore offer an important field for nutritional research.

PRACTICES IN THE FEEDING OF BEEF AND DUAL-PURPOSE CATTLE

by W. H. Black[1]

IN A COUNTRY as varied as the United States, feeding practices with beef cattle differ considerably in different areas. The author of this article discusses his subject with these differences in mind. Some of the newer experiments and methods, including the creep feeding of calves, are described from the standpoint of their practical value or lack of value. A table at the end of the article gives suggested average rations, in terms of the common feeds, for various classes of cattle.

BEEF CATTLE

PRACTICES used in the feeding of beef cattle depend to a large extent on the relative availability of suitable grasses and grain. Where grass is the principal asset, as in the range country, and where grain or other concentrates are rather limited, the practices employed will or should be based on the maximum use of grass supplemented in some instances with hay, grain, highly concentrated feeds, or combinations of these. This will apply to essentially all methods or phases of beef-cattle feeding, including wintering, summer grazing, and fattening. Therefore, where grass is the primary feed and concentrates are limited, the feeding practices are likely to be associated with the wintering and summer grazing of breeding herds and steers of various ages for feeder production rather than with the production of finished beef.

In such areas as the Corn Belt, where fattening feeds are usually abundant and where pastures are somewhat limited, the extensive use of grain for steer fattening, and to a lesser extent for breeding herds, is the common feeding practice. But whether it be in the range country of the West, the fattening areas of the Middle West, or other beef-production areas, the feeding practices to use will hinge on the place filled by grass in the ration. In the broad sense, it is either grass or grain with the beef cattleman. There are, of course, many modifications of these two practices within and between the various beef-production areas, and these will be discussed under wintering, summer grazing, and fattening.

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[1] W. H. Black, Senior Animal Husbandman, is in charge of the Office of Beef and Dual-Purpose Cattle Investigations, Animal Husbandry Division, Bureau of Animal Industry. Acknowledgment is made by the author for the valuable assistance in the preparation of the dual-purpose material of A. C. Cook, Associate Animal Husbandman, Animal Husbandry Division, in charge of records on beef and dual-purpose cattle, Agricultural Research Center, Beltsville, Md.

WINTERING BEEF CATTLE

Wintering beef cattle is an economic as well as a nutritional problem. The objective is to meet the minimum requirements of the animals for existence without impairment of function with feeds that are available and cheap and can be easily transported. Slightly different feeding practices are followed with breeding herds, bulls, and steers.

Breeding Herds

The breeding herd, generally speaking, is wintered in the feed lot. The tendency to reserve range or pastures for winter grazing is rapidly increasing, however. In the range country of the Southwest and in the Southern States, particularly along the Gulf coast, thousands of cattle have always had to depend upon range the year round; as a result death losses are usually quite heavy, and while the majority come through, the ill effects of undernutrition are usually clearly revealed in their poor condition and small size. To remedy this situation is a big problem in many localities, such as the cut-over pinelands, where it is difficult to improve the range by the introduction of better grasses or to grow supplementary feed, especially during the winter months. Perhaps the most practical way to improve the methods of wintering beef cattle under these conditions is to feed a supplement of concentrates. Cottonseed cake has been used rather extensively throughout the Great Plains region as a supplement to winter range.

At the United States Range Livestock Experiment Station, Miles City, Mont., experiments during 1929–34 (*113*)[2] showed that in 3 years out of 5 it was possible to keep the breeding cows on the range all winter. One group of the cows kept on the range throughout the winter received no supplemental feed, while the other received cottonseed cake in an amount averaging 91 pounds per head for the total average winter period of 156 days. Cows fed cake made a winter gain of 23 pounds per head, whereas those on range alone lost about 11 pounds. At the end of the following grazing season, however, there was a difference in yearly loss per cow of only 13 pounds, those fed cake during the winter losing 19 pounds as compared to 32 pounds for those wintered on the range without supplement. The loss in weight during the summer grazing seasons for the supplement-fed cows was 42 pounds, twice that of those carried on range alone. Calves from cows fed cottonseed cake were about 2 pounds heavier at birth and 13.6 pounds heavier at weaning time. The winter feed cost for the cottonseed-cake fed cows was $2.02 greater per cow, and the cost per 100 pounds of calf produced was $0.60 more than in the herd receiving no supplement. These results indicate that the use of cottonseed cake should be limited to seasons in which winter range conditions are severe. The experiments also showed that 1 pound of cake replaces approximately 10 pounds of hay fed in the feed lot.

It should be taken into consideration that the range used in these experiments was typical of the northern Great Plains region, consisting largely of western wheatgrass, blue grama, and buffalo grass. Grazing was therefore somewhat better than that found in the southern part of the Great Plains and decidedly superior to that on native range in the Southeastern States. Progressive cattlemen have found, however, that from 1 to 2 pounds of cottonseed cake a head daily or its equivalent in grain or hay will usually carry breeding cows or growing stock 1 year old or older through the winter if they have access to reasonably good range for the area and if the season is normal.

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[2] Italic numbers in parentheses refer to Literature Cited, p. 1075.

Other highly concentrated feeds will undoubtedly come into prominence for use in wintering beef cattle on the range. Up to the present time, the supplements for the most part have been protein-rich feeds such as cottonseed and linseed cake, but there is now a growing opinion that energy (carbohydrates and fats) is equally as important as a range supplement as protein—admitting that the protein-rich concentrates supply some energy. In view of this, some feed manufacturers are already putting on the market feeds in cube or pellet form which supply both protein and energy. Such feeds as beet pulp, alfalfa, molasses, and protein-rich meals are being used in the manufacture of these newer types of feeds.

Whether cattle using winter range, which is usually deficient in nutrients at best, require additional protein only, energy only, or a balanced supplement, will have to be determined by carefully controlled experiments. This problem should be worked out by State experiment stations for specific areas, since what may be found to be true in one area may not be the best for others, owing to differences in the plant species making up the bulk of the grazing.

In areas where winter range cannot be provided, some form of dry roughage (principally hays), or silages supplemented in some instances with grain or protein concentrates, or both hay and silage, may be used for wintering cows. There are few areas where either hay or silage crops cannot be produced. The place of silage made from corn, sweet sorghums (sorgos), and grain sorghums in the winter feeding of the breeding herd is well known in the areas where these crops are produced. It may not be amiss to mention that good-quality silage from these crops, when supplemented with small quantities of grain and dry roughage, is one of the most economical and otherwise satisfactory feeds for wintering breeding, feeder, and stocker beef cattle. The use and value of good-quality hays for wintering beef cattle are likewise known. Suggested hay and silage rations for various classes of beef cattle are given in table 2 (p. 564).

In some areas, particularly the South, many forage and hay crops are produced, but owing to the humid climate, it is impossible to cure them as fodder or hay. New processes by which legumes or grasses can be ensiled with safety are already beyond the experimental stage. Two methods now being employed in the making of silage from these crops are by the addition of molasses[3] and of acids (*854*, *1169*).[4] The use of molasses in the making of silage from legumes and grasses is no longer experimental. The preservation of silage by the use of mineral acids, such as phosphoric, offers possibilities, but so far has not been resorted to as extensively as the preservation by molasses. Further experimentation is needed in this field.

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[3] WISCONSIN AGRICULTURAL EXPERIMENT STATION. MAKING MOLASSES LEGUME SILAGE. Wis. Agr. Expt. Sta. Spec. Bull., 6 pp., illus. 1936 (rev. 1938). [Mimeographed.]

[4] VIRTANEN, A. I. THE A. I. V. METHOD OF ENSILAGE. Lecture . . . in Stockholm during Swedish Agriculture Week, March 15, 1932. 28 pp. [Typewritten copy in Bur. Anim. Indus., Beef and Dual-Purpose Cattle Investigations.]

The quantities of molasses used per ton of green material are approximately as follows (*854*):

Kind of crop:	Molasses per ton
Grasses or cereals	40 pounds (3½ gallons)
Mixed grasses and legumes	60 pounds (5 gallons)
Alfalfa or clovers	80 pounds (7 gallons)
Soybeans	100 pounds (8½ gallons)

A survey (*854*) of the results on 34 farms showed that 16 pounds (1¼ gallons) of phosphoric acid to 1 ton of green material gave satisfactory results. Where smaller quantities of the acid were used, severe spoilage resulted.

The making of grass and legume silage by use of molasses, and perhaps of acids, should have great adaptability to the Southeastern States and the Gulf coast region, where the harvesting seasons for hay are usually marked by frequent rainy spells.

In the feeding of grass or legume silage, the fact should not be overlooked that the protein content is much higher than it is in corn silage. Alfalfa silage, for example, will supply approximately twice as much protein as an equal unit of corn silage. The use of grass silage will therefore make possible a reduction in the quantity of protein-rich concentrates usually fed with silage.

In range operations it is often desirable to carry hay over from one season to the next or for a number of years. Such hay deteriorates in nutritive value particularly with regard to carotene. Small quantities of new hay or silage can be used to advantage to supplement old hay.

Breeding cows should be wintered so as to be in thrifty condition in the spring. If they enter the winter season in good flesh, it is not necessary for them to make gains in weight during this period. It is, however, important that cows in good flesh have no appreciable weight loss during the winter. Cows going into the winter in thin flesh should be well wintered in order not only to increase their weight, but also to properly nourish the fetus. Suggested winter rations for cows under various conditions will be found in table 2 (p. 564).

In well-managed herds, the breeding operations are controlled so that calves will be dropped in the spring. Emphasis should be placed on the wintering of young heifers as calves and yearlings. After the second winter they are usually turned in with the breeding herd and handled as mature cows. As calves, they should be given the opportunity for proper growth and development through liberal feeding during the winter season which usually follows weaning. There are few localities where it would be advisable to attempt to winter calves on the range. In the warmer climates, improved ranges or pastures that have been reserved for winter grazing may be used, but even then supplemental feed such as grain, protein concentrates, and legume hay should be provided. Heifer calves intended for breeders should be fed so as to gain from ¾ to 1 pound per head daily during the winter.

Results of experiments (*112*) extending from the winter of 1926–27 through the summer grazing season of 1929 at Miles City, Mont., showed that calves could be wintered satisfactorily on alfalfa hay alone at the rate of 13 pounds per calf per day. When 0.7 pound of cottonseed cake was added to a hay ration of 12 pounds, the rate of winter gain was increased but the subsequent summer gains were correspondingly decreased, indicating that the addition of cottonseed cake to an alfalfa-hay ration for calves was neither essential from a nutritional nor economical from a feed-cost point of view. The replacement of 3.6 pounds of alfalfa hay by 9 pounds of corn silage doubled the winter gain, but at the end of the following summer grazing season, the calves fed alfalfa hay and corn silage were only 18 pounds heavier than calves fed hay alone. Supplementing alfalfa hay should be desirable only when maximum gains are desired and an early sale of the animals is anticipated. The results of these experiments should be applicable to many beef-production areas throughout the United States.

Experiments conducted by the New Mexico Agricultural Experiment Station (*662*), in which heifer calves were wintered on range supplemented with varying quantities of cottonseed cakes, showed that one-half pound of cake per head daily increased the total gain per heifer 42 pounds over those receiving no supplement. When greater quantities of cake were fed, winter gains were further increased but subsequent summer gains were decreased, indicating more efficient production for the calves fed one-half pound of cake per head daily. These results may be considered as applicable to most range areas.

In wintering yearling heifers on the range, the New Mexico station (*662*) found that it was advisable to feed approximately 1 pound of cottonseed cake per head daily. The ultimate benefit derived from such feeding is not so much the effect on the weight of the cow as the fact that it enables the dam to produce considerably more milk, resulting in rapid gains for the suckling calf.

Experiments (*55*) at Miles City, Mont., showed that yearling heifers could be wintered satisfactorily in the feed lot when fed at the rate of approximately 20 pounds of good hay per head per day. The average rations used for two groups over a 3-year period were 22.7 pounds of alfalfa hay and 20 pounds of western wheatgrass hay, which gave winter gains of 38 and 40 pounds, respectively. Additional rations suitable for growing heifers wintered on the range as well as in the feed lot will be found in table 2 (p. 564).

Bulls

Bulls are wintered under essentially the same procedure regardless of the area or locality. The common practice is to winter them in sheds or feed lots and to feed them liberally on grain, protein concentrates, and roughage (hay, silage, or both).

It is essential to have the bull in a thrifty condition at the beginning of the breeding season, which, except in the Southern States, is usually about July 1. Bulls liberally fed during the winter months are likely to become too fat if not allowed to get considerable exercise. Bulls should have access to paddocks or small pastures and be compelled to take exercise.

Winter range is desirable for bulls if it is provided with shelter and conveniently located so that supplemental feed can be provided each day. Feeding grain at the rate of ½ to 1 pound per 100 pounds of live weight with good range should be sufficient for properly wintering bulls that enter the winter in a thrifty condition.

Where range is not available, roughage such as good-quality legume hay should be fed at the rate of approximately 1½ to 2 pounds per 100 pounds live weight, or half this quantity with about 3 pounds of silage per 100 pounds live weight per head daily. Suggested rations for bulls are given in table 2 (p. 564).

Steers

Methods of wintering steer calves are similar to those employed for heifers, and the feeding practices recommended for heifer calves may be applied to steer calves.

In experiments during 1930–31 to 1934 (*115*) in the wintering of steers at the United States Range Livestock Experiment Station, steers were carried through two winters—as calves and yearlings—on high, medium, and low planes of nutrition, followed by two summer grazing seasons. No significant differences were apparent in average final weights of the three groups at the end of the summer grazing when the steers were approximately 2½ years old. The average winter rations fed during the three experiments were as follows: The steers on a high plane of nutrition (group 1) received as calves 1.13 pounds of concentrates, 11.97 pounds of alfalfa hay, and 0.59 pound of straw; and as yearlings, 0.09 pound of concentrates, 20.76 pounds of hay, and 1.86 pounds of straw or straw and stover. The steers in group 2, on a medium plane of nutrition, received as calves 8.34 pounds of alfalfa and 4.01 pounds of straw or straw and stover; and as yearlings 9.65 pounds of alfalfa hay and 8.58 pounds of straw or straw and stover. The steers on a low plane, group 3, received 3.74 pounds of alfalfa hay and 7.31 pounds of straw or straw and stover as calves and as yearlings, 4.22 pounds of alfalfa hay and 13.60 pounds of straw or straw and stover. Shredded corn stover was used to replace the straw in a part of the 1931–32 experiment.

The group 1 steers made a total average gain of 169 pounds per head for the two winters, as compared to 93 pounds for those in group 2, and 39 for group 3. The 2½-year-old steers averaged at the end of the summer grazing season 1,068, 1,036, and 1,031 pounds, respectively, for the steers carried on the high, medium, and low planes of winter feeding. Any increased gain between groups did not compensate for the increased production costs. Steers on the low plane made greatest use of the summer range, as revealed by increased summer gains. The steers wintered on the high plane made 74 percent of their total winter and summer gain on the range, as compared to 85 percent for those on the medium plane, and 94 percent for the low-plane steers. These experiments showed rather conclusively that, if steer calves in a thrifty condition are to be developed into 2-year-old feeder steers by the use of native summer range, they should be wintered so as to gain 25 to 50 pounds per head during their first winter and kept in a thrifty condition on a plane slightly above maintenance during their second winter, as yearlings.

These experiments have been discussed rather fully because the principles involved and results obtained are more or less applicable to any feeder-production area in the United States.

Experiments in wintering yearling steers (1933–36) in southwestern South Dakota (*107*) on the range with and without supplements and in the dry lot, showed that under the conditions prevailing the costs for wintering the steers on the range was only 40 percent of that for the steers wintered in dry lot, and that the feeding of supplements to steers on the winter range may be limited to days of extremely cold weather or when the vegetation is snow-covered. Supplemental rations of 0.78 pound of cottonseed cake and 1.51 pounds of corn produced similar winter gains at approximately the same cost, which averaged $1.63 more per head than for the steers wintered on the range and fed alfalfa hay only during severe weather or periods of heavy snowfall.

Suggested rations for wintering steers of various ages are given in table 2 (p. 564).

SUMMER GRAZING

Most classes of beef cattle are turned on the summer range or pasture and forgotten until frost appears in the fall (fig. 1). There is accordingly little difference among practices within and between the areas of beef production. Rates of stocking and methods of handling pastures are the important summer grazing problems from a nutritional point of view. From the point of view of beef cattlemen, pastures are measured by the pounds of steer gain per acre or the number of breeding cattle that can be grazed on a given unit without injury to the pasture or range. These measurements are influenced to a large extent by methods of fertilizer treatment, which is outside the province of this article. Methods of managing cattle on pastures and ranges and of supplementing native pastures are considered here, and the feeding of supplements for the production of slaughter cattle is discussed under fattening practices (pp. 552–562).

Experiments by Hein and Cook (*502*) conducted at Beltsville, Md., showed that no significant differences in gains were made by yearling steers on pastures grazed heavily and alternately and on pastures grazed heavily and continuously at the rate of one head per acre over a 6-year period. Steers on a pasture grazed lightly and continuously, stocked at the rate of one animal to 2 acres, made an average summer gain of 287 pounds per head as compared with an average gain of 195 pounds for the steers on the pastures heavily grazed. The average steer gain per acre for the 6-year period was 145 pounds for the lightly grazed pastures and 195 pounds for the pastures stocked at the heavier rate.

It should be taken into consideration that when pastures are not closely grazed, there will, in normal seasons, be surplus forage that can be used for thin feeder or stocker cattle in the late fall and early winter. When pastures are grazed heavily, some provision should be made for supplemental feed on pasture during late summer when plant growth is retarded by hot weather and lack of rainfall.

Experiments in progress at Grain Valley, Mo.,[5] indicate the advisability of supplementing bluegrass pastures with Korean lespedeza during the latter part of July and through August. A supplemental

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[5] Unpublished data obtained in cooperative experiments between the Bureaus of Plant and Animal Industry and the Missouri Agricultural Experiment Station.

Figure 1.—In the summer, most classes of beef cattle are turned out on the range or pasture and forgotten until frost appears in the fall. Rates of stocking the range and methods of handling pastures are the important nutritional problems.

acreage of Korean lespedeza, representing a 40-percent additional acreage, increased the steer gains 70 percent and enhanced the sales value of the steers an estimated 50 cents per hundredweight. The results of these experiments are quite generally applicable to the Middle Western and Eastern States.

Experiments at Ardmore, S. Dak., over a period of years (1919–30) (*106*) showed that the vegetation making up the pasturage is not likely to be damaged by cattle if grazing is delayed until the middle of May and provided the rate of stocking is such that the cattle make fair gains during the growing season. Some loss in weight shown by cattle during the fall months does not necessarily mean that the carrying capacity of the range is impaired. Pastures that were more intensively grazed produced greater gains per acre for the season than the pastures less intensively grazed. A slight advantage was shown in steer gains and gains per acre for alternate grazing over continuous. It should be well understood, however, that it is not impossible to injure pastures and ranges by overgrazing. The unlimited use of public domain in many sections of the Great Plains in the past has demonstrated time and again the evils of overgrazing.

FATTENING BEEF CATTLE

Two general methods are employed in the fattening of beef cattle for slaughter purposes: (1) Fattening on grass, (2) fattening in the dry lot. Many practices are in use under each method. As the great bulk of beef cattle fattened are steers, the discussions which follow will apply to this class of cattle.

Creep-Feeding Calves

In recent years there has been an increasing demand for lighter cuts of meat on the beef market in the United States. In an attempt to satisfy this changing demand, producers have striven to have cattle fat enough for slaughter when they are comparatively young (fig. 2). The more economical use of grain by younger cattle has been a contributing factor in the growth of this practice, though the ability of older cattle to make extensive use of roughage not otherwise marketable has offset this advantage to some extent. However, when calves to be fattened are raised instead of purchased, the breeding herd of beef cows utilizes to advantage coarse roughages that are less suitable for calves. Consequently, the maintenance of a breeding herd and the fattening of the calves produced may replace the grazing and fattening of older cattle on many farms.

To meet the demand for smaller cuts of beef and to produce beef more economically, it has been found practical, under certain conditions, to full-feed well-bred beef calves grain or concentrate mixtures previous to weaning and have them fat enough for slaughter at weaning time or a few months thereafter. This practice is termed "creep feeding." Three years of cooperative work by the United States Department of Agriculture and the University of Missouri at Sni-A-Bar Farms, Grain Valley, Mo., showed that grain-fed calves weighed about 100 pounds more at weaning time than similar calves fed no grain and were usually fat enough for slaughter when weaned at 8 months of age (*117*). When such calves were not marketed at

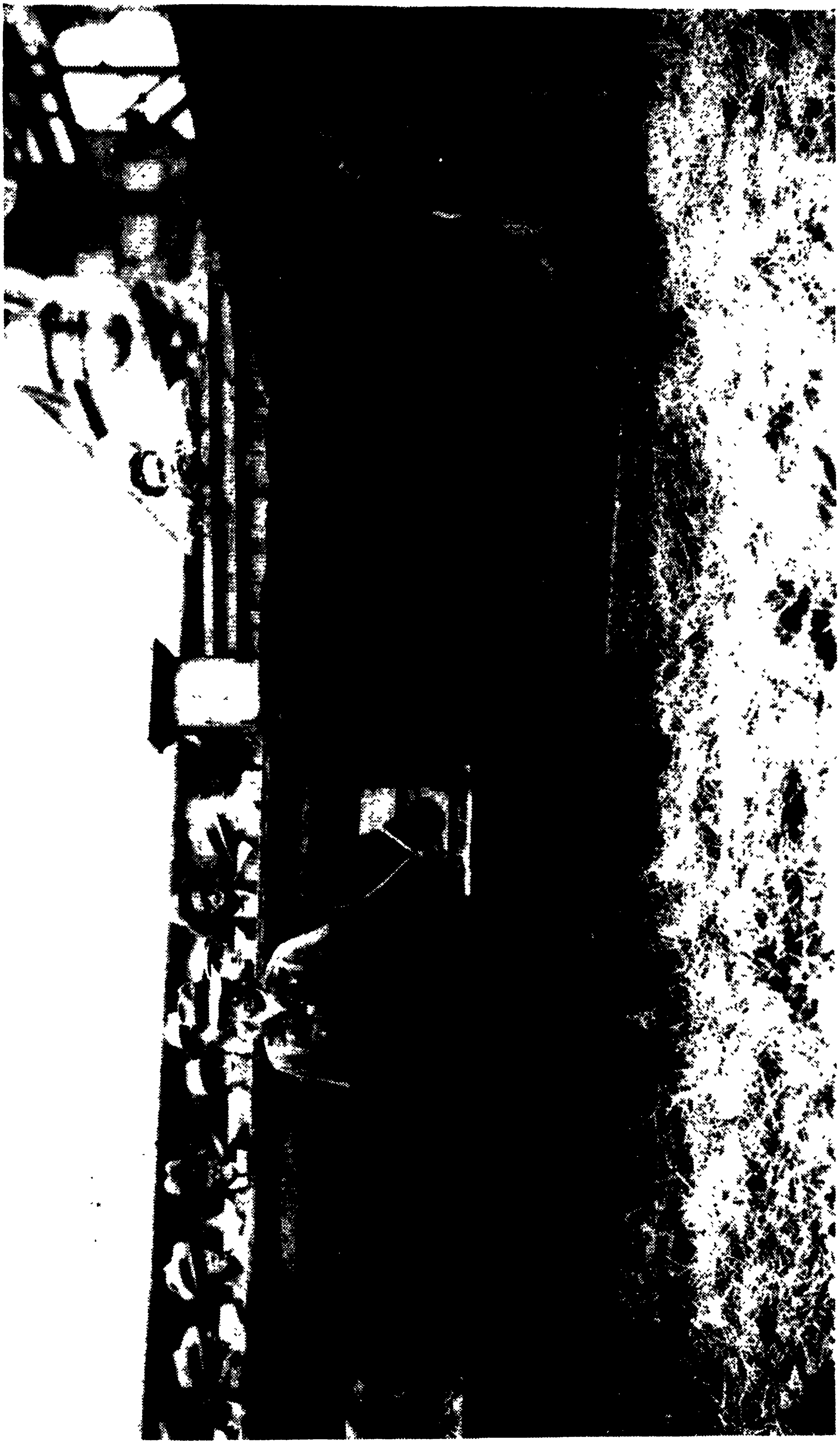

Figure 2.—To meet the increasing demand for lighter cuts of beef, fattening calves for market may replace the grazing and fattening of older cattle on many farms. The steer at the left is fat enough for market at less than a year old.

weaning time, the practice of feeding grain before weaning shortened the subsequent feeding period.

The most suitable grain ration for such feeding became a problem of importance. In 3 years of cooperative feeding tests (*118*) at Sni-A-Bar Farms comparing (1) shelled corn alone, (2) shelled corn, 8 parts by weight, and cottonseed cake, 1 part, and (3) shelled corn, 2 parts by weight, and oats, 1 part, it was found that suckling calves fed 140 days consumed less grain per 100 pounds of gain when fed shelled corn alone than when fed either of the other two rations. However, the calves fed the shelled corn and cottonseed cake made greater gains, were fatter, and were valued 50 cents per 100 pounds higher at weaning time than those fed corn alone or the corn-oats mixture. The increased value of the calves fed shelled corn and cottonseed cake and their greater gains more than offset the cost of the increased feed consumed.

Subsequent creep-feeding experiments (*120*) at Grain Valley over a 2-year period, showed that the addition of an alfalfa-molasses supplement to a shelled-corn and cottonseed-cake ration in which the corn was ground resulted in a mixture that required 25 percent more feed per 100 pounds of gain than did the unground shelled corn and cottonseed cake. The higher and more economical gains of the calves fed shelled corn and cake more than offset a slightly higher valuation of the calves fed ground grain with the molasses supplement. Grinding increased cost of gains significantly but did not materially affect the rate of gain or the values of the calves.

McComas and Wilson (*726*) found, in experiments conducted over a 3-year period in West Virginia, that a grain ration (8 parts shelled corn and 1 part cottonseed meal by weight) fed to spring calves during the period previous to weaning, while they were running with their dams on good bluegrass pasture, increased the calf gain 8 percent over that for similar calves not creep-fed. Calves creep-fed for 168 days were suitable for slaughter at weaning time at an average age of 230 days for the group, whereas those not creep-fed were strictly feeders. In these experiments, the calves not creep-fed were placed in a feed lot and fattened for an average period of 116 days for the 3 years, to determine which method of feeding grain to calves was preferable—that is, feeding the grain previous to weaning by the creep system or in the dry lot following weaning. The average grain ration for the calves fattened in the dry lot was approximately 8 pounds of the grain mixture and 3.75 pounds of hay per day.

An important point in the creep-feeding method is the relatively small quantity of grain supplement required per 100 pounds of calf gain. In these experiments, this amounted to 125 pounds for the creep-fed calves and 688 for those fattened in the dry lot. The net returns per calf were slightly, but not significantly, higher for the dry-lot-fattened calves. In the Sni-A-Bar experiments (*120*), there were no significant differences in average net returns per calf between those fed supplements for 140 days before weaning and those continued on those supplements for 196 days after weaning.

Taylor, Willham, and Hawkins (*1122*) conducted experiments to study the effect of feeding grain to calves while they are nursing as compared to no grain while nursing, both lots of calves to be full-fed in the dry lot after weaning. They reported that creep-fed calves started the dry-lot fattening experiment following weaning at 50 pounds heavier than non-creep-fed calves, but owing to a slower rate of gain were only 4 pounds heavier at the close of the test. The results showed that creep feeding does not pay for calves that are to be full-fed on grain for 5 months or more after weaning. The practice of creep feeding is better suited to farming conditions than to range areas. On farms the herd can be confined to relatively small pastures with only one watering place, preferably located near shade where the herd will tend to congregate for rest.

Fattening Steers on Grass

Comparatively few areas in the United States produce highly finished beef on grass alone. However, very creditable strictly grass-fattened beef comes from the Appalachian region, the Flint Hills and sand-hill areas of Kansas and Nebraska, respectively, the Osage country of northern Oklahoma, the Mineral Point section of Wisconsin, and many sections of the Great Plains. Thousands of grass-fat steers and even greater numbers of feeder cattle are marketed annually from the areas mentioned. Feeder cattle require and receive more finish by fattening in the grain-production areas, principally the Corn Belt. Great numbers of 2- and 3-year-old steers are sent into the Flint Hills and Osage country from Texas in the spring for strictly grass fattening. The bulk of these cattle usually move to the river markets in the Middle West during August and September for slaughter.

There has been a noticeable trend in late years in many grass areas (exclusive of the strictly range areas) to supplement grass with concentrates. Generally speaking, fattening cattle on grass requires only about one-half the quantity of grain or other concentrates that strictly dry-lot fattening requires. The practice of supplementing the grass with grain for production of grass-grain finished steers is well suited to areas where the bulk of farm land is in grass with a limited acreage devoted to grain production.

Three years of experimentation by Black, Warner, and Wilson (*121*) in the Appalachian region in West Virginia showed rather conclusively that the feeding of grain (corn and cottonseed meal) was advisable for fattening steers on grass, as the gains of the steers were increased 37 percent and the selling price more than 10 percent. These increases in steer gain and sale price were sufficient to more than offset the additional expense incurred over that for the strictly grass cattle. It should be taken into consideration, however, that the buying and selling prices of the cattle may have a more direct bearing on the profits than feed costs, and accordingly the feeding of grain to steers on grass may not necessarily be done at a profit. Grain increased the dressing percentage and produced fatter, more attractive, salable carcasses.

These experiments were immediately followed with another series [6] to study the relative values of different methods of feeding the supplement. The average results during the 3-year period showed that the sales value of the steers fed grain throughout the grazing season of 135 days was increased $1.13 per hundredweight over that of strictly grass steers, but only 8 cents over the sales value of similar steers fed grain only during the last 79 days of the grazing period. This fact indicates that the feeding of grain supplements to steers on grass during the first half of the grazing season, provided grazing conditions are good, is not necessary for best results. The results also indicate that the practice of feeding a limited grain ration during the last half of the grazing season is to be preferred to the feeding of a more liberal ration of grain and hay in the dry lot for a short period immediately following the summer grazing season. The results of these experiments in the bluegrass region of West Virginia should be applicable to all bluegrass regions and to many other sections having improved pastures.

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[6] Experiments conducted at Lewisburg, W. Va., by the West Virginia Agricultural Experiment Station and the Bureau of Animal Industry, 1928 to 1931. Data unpublished.

There has been very little research to determine the value of feeding grain to steers on native grass in the range areas, due primarily, of course, to the scarcity of grain. However, in range areas adjacent to irrigation sections, or where dry-farming is practiced, as in the semiarid districts, the use of grain in a limited way for fattening steers on the range may be justifiable. The shipping of grain for this purpose into the range areas from a considerable distance is not recommended.

Experiments by Black and Clark (*107*) in southwestern South Dakota, in which steers were fed grain (wheat and barley) on native summer range, showed that the feeding to 2-year-old steers of a grain supplement increased the steer gains materially over those made by steers on range without supplemental feed. In these experiments the increased cost of gains due to the use of supplemental feed was more than offset by the increased sales value of the steers as a result of more finish. The feeding of grain made it possible to market slaughter cattle rather than feeders. The grain used in these experiments was produced locally under dry-land farming conditions. As in the West Virginia experiments, there was no significant advantage in feeding the supplement throughout the summer grazing season rather than only in the last half.

Fattening Steers in the Dry Lot

The range areas west of the one hundredth meridian, extending from Canada to Mexico and including the Rocky Mountain region, supply the bulk of feeder cattle. Approximately one-third of these cattle are shipped to the Corn Belt for fattening (fig. 3). Of the remainder, some are shipped to other fattening areas in the Appalachian region, some are sent to grass areas within the range country for grass fattening, as exemplified by the movement of Texas cattle to the Kansas Flint Hills, and still others are fattened within the range area on such feeds as the grain sorghums and cottonseed and on beet products. The feeder cattle are shipped to the grain-finishing areas primarily as calves and yearlings, a tendency toward the feeding of calves being on the increase. The feeders to be grass-fattened are usually 2 years old or older.

The feeding of various ages or grades as such will not be discussed in this article, but rather the different practices or methods of fattening within the areas, with special reference to types and combinations of feeds used. A review of table 1 will perhaps be of interest, however. This table gives the approximate feed units required to produce 100 pounds of gain on cattle fed in the dry lot as reported by Wilcox, Jennings, Collier, Black, and McComas (*1219, p. 45*).

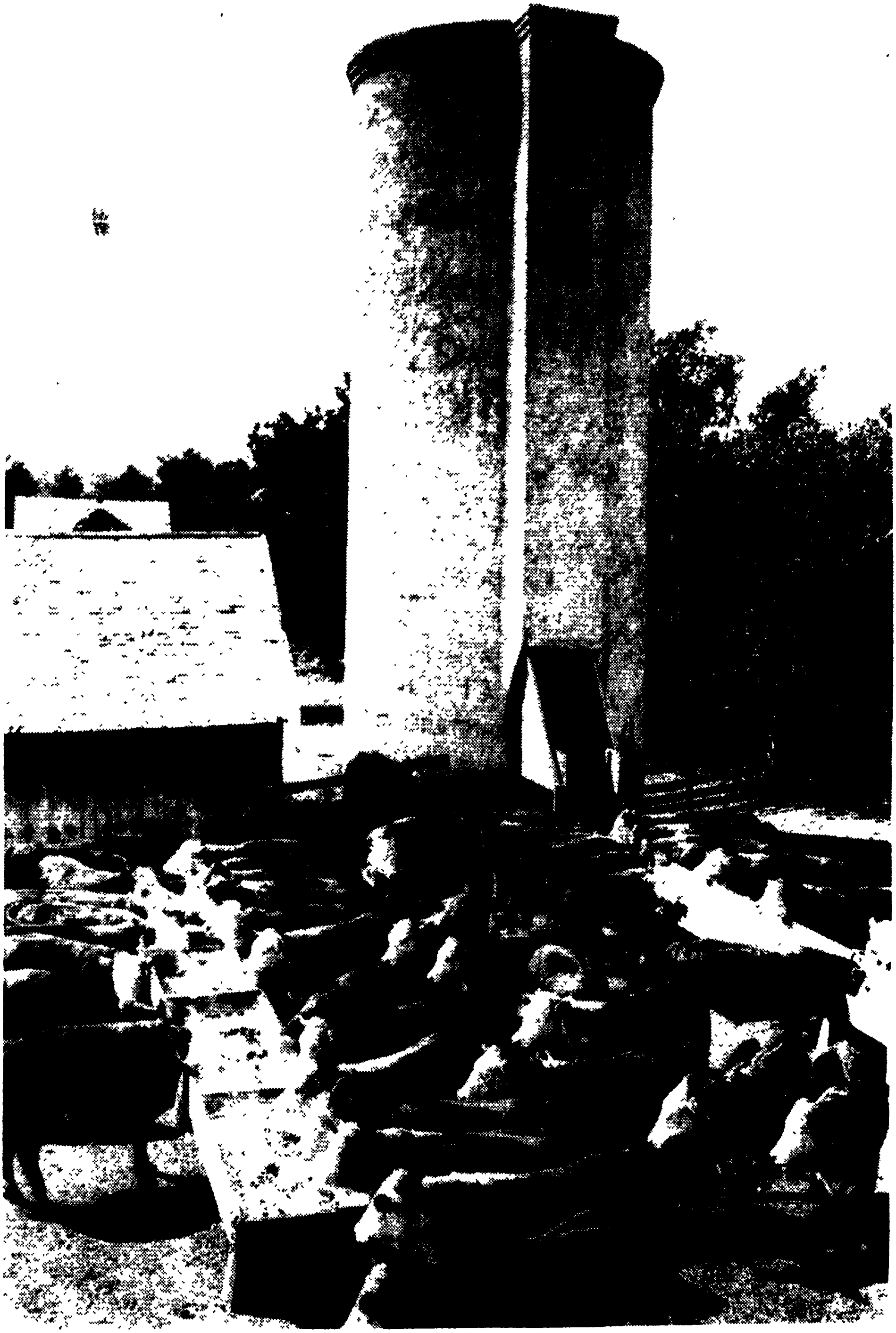

Figure 3.—Dry-lot feeding in the Corn Belt. Rations for fattening steers in the dry lot vary considerably, especially as between silage and legume hay.

TABLE 1.—*Feed units [1] required to produce 100 pounds of gain on cattle fed in dry lot*

Weight group (pounds)	Concentrates	Dry roughage	Silage	Total feed units	Percentage of requirements for heavy cattle
	Units [1]	*Units* [1]	*Units* [1]	*Units* [1]	*Percent*
Heavy cattle (over 1,000)	1, 109	150	71	1, 330	100
Medium-weight cattle (751–1,000)	841	151	168	1, 160	87
Yearlings (501–750)	691	138	173	1, 002	75
Calves (under 500)	682	110	65	857	64

[1] After due consideration of the analyses of the feeds and of the values given to them in various feeding standards, they were put on a unit basis as follows:

1 pound corn	1.00 unit	1 pound mixed hay	0.35 unit
1 pound protein concentrate	1.30 units	1 pound stover and straw	.25 unit
1 pound legume hay	.45 unit	1 pound corn silage	.17 unit

Rations of fattening steers vary considerably between areas, and in the Corn Belt there are many variations in type of rations fed. In Iowa and Nebraska legume hay makes up the bulk of the roughage, whereas in Illinois and Indiana, corn silage and mixed hay are more widely used. A 5-year (1919–23) study (*1219*) of cattle-feeding practices in the Corn Belt showed that in eastern Nebraska only 2 percent of the rations contained silage and 76 percent contained legume hay, whereas in north-central Illinois 85 percent contained silage and only 26 percent contained legume hay. The use of silage, particularly in the Corn Belt, is governed usually by the quantity of legume and other dry roughage available, the price of grain, and the condition of the corn crop as regards maturity. When corn fails to mature, owing to short seasons and early frosts, the crop can be ensiled and used very satisfactorily for cattle feeding. Silage, as already indicated, replaces not only hay, but also grain. As silage is used largely with mixed hay or other roughage, such as straw or stover, it is usually advisable to include a protein-rich concentrate, such as cottonseed meal, linseed meal, soybean meal, or tankage.

Silage is better suited to the early part of the fattening period, when greater quantities of roughages can be used advantageously. Silage can probably be used more satisfactorily with the lower grades of cattle that are not intended to be fattened to a high condition. It is also more suitable for long periods when rapid steer gains are not necessarily desired.

The Minnesota Agricultural Experiment Station[7] treated corn silage with phosphoric acid at the time of filling the silo to determine whether the feeding value of the silage could be increased. In this experiment about 10 gallons of the diluted mixture containing 10 pounds of phosphoric acid were used per ton of green corn. The results showed that while the silage treated with phosphoric acid kept it in excellent condition and possessed a dark-green, natural fresh-cut silage color, there was no increased feeding value as revealed in steer gains. In the same experiment the addition of bonemeal did not show any benefits

In the Corn Belt one of the more important problems in the fattening of cattle is the source of protein. Generally speaking, the protein concentrate that will supply a pound of protein most cheaply should be the one to use, whether it be tankage, linseed meal, cottonseed meal, or some other product. All of these meals or feeds, of course, contain some energy and fat as well as protein, but usually the Corn Belt cattle feeder is interested only in protein and not in paying transportation on ingredients he already has at hand. It is only in late years that tankage has been used in cattle feeding. It is not so palatable to cattle as the more widely used meals, but after a week little difficulty is experienced in getting cattle to eat rations containing tankage. Experiments by Johnson and Peters [8] show no advantage for tankage over linseed meal for fattening 450-pound calves fed at the rate of 1.5 pounds of linseed meal or 0.9 pound of tankage per head daily, unless a pound of protein can be obtained more cheaply in tankage than in other protein supplements.

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[7] PETERS, W. H., and ROGERS, C. F. THE FEEDING VALUE FOR FATTENING CATTLE OF CORN SILAGE TREATED WITH PHOSPHORIC ACID WHEN FED TO ¡FATTENING CATTLE. Minn. Agr. Expt. Sta. Rept. B-32, 5 pp. 1936. [Mimeographed.]

In the absence of corn, such cereal grains as barley, rye, oats, and wheat are used in many sections of the Northern and Pacific Coast States. In the Southwest the grain sorghums are used very extensively as both grain and silage. In the sugar-beet areas, beet pulp and molasses are used, and in the Cotton Belt, cottonseed meal and hulls make up the standard cattle-fattening ration. According to Wilson and Wright (*1237*) in South Dakota, barley as a single feed is not equal to corn for fattening 2-year-old steers, since about one-eighth more barley was required for the same unit of gain. This would mean that barley was about 88 percent as efficient as corn for fattening 2-year-old steers. These same experimenters (*1238*) in comparing rye (ground and unground) with shelled corn, when fed in conjunction with alfalfa hay, found that the steers fed ground rye consumed about twice the quantity of hay, and those fed unground rye about one-third more than the steers fed shelled corn, which indicated a vast difference in palatability of the two feeds. The rye-fed groups, instead of fattening, tended to grow, indicating an absence of the necessary nutrients for fattening.

Stanley (*1097*) found, in two trials, no differences in the relative feeding value of rolled barley and hegari (a grain sorghum) when fed to high-grade range-bred calves weighing from 375 to 450 pounds. The addition of a simple mineral mixture composed of equal parts of steamed bonemeal and finely ground limestone to a ration of alfalfa hay, rolled barley, and cottonseed meal did not prove profitable, nor were any beneficial results apparent (one trial).

Barley fed to fattening cattle frequently causes digestive disorders, principally in the form of bloat. No satisfactory method for preventing this trouble has been worked out. It is the consensus of opinion, however, that when cattle have access to dry roughage such as straw or stover there is less trouble from bloating due to barley.

Oats are generally considered too expensive a feed for cattle-fattening purposes. There are times, however, even in the Corn Belt when the feeding of oats to cattle is to be recommended. The addition of oats to the ration makes possible a reduction in the quantity of protein concentrates such as linseed or cottonseed meal, owing to the higher percentage of protein in oats as compared with corn. Frequently the oat crop is of inferior quality, the oats being lightweight and very cheap, and under these conditions, especially when corn is comparatively high in price, it is advisable to replace corn in part at least by oats. Rogers and Gerlaugh (*979, p. 172*) found at the Ohio Agricultural Experiment Station that oats made a very satisfactory substitute for half of the shelled corn in a ration for fattening yearling steers for a period of 140 days, especially when both oats and corn were valued at the same price per pound.

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[8] JOHNSON, D. W., and PETERS, W. H. LINSEED OIL MEAL AND TANKAGE FOR CATTLE FATTENING. Minn. Agr. Expt. Sta. Rept. B-31, 8 pp. 1935. [Mimeographed.]

Wheat, like oats, is usually too expensive for cattle feeding. There are times, however, when the quality is inferior owing to drought or an otherwise unfavorable growing season, and it can be used advantageously to replace corn in the fattening ration. Good-quality wheat should be nearly as valuable as corn.

The grain sorghums are coming into prominence in steer-fattening rations as both grain and silage. Early experiments (*108, 110*) in Texas and New Mexico indicated that the results from the feeding of grain from sorghums to fattening steers compared favorably with those from corn for beef production. Fodder and silage from the sorghums were likewise found to be valuable sources of roughage in beef-cattle rations.

Subsequent experiments by Black, Jones, and Keating (*109*) showed that steers fed ad libitum on ground milo in conjunction with Sumac sorghum fodder and cottonseed meal made greater gains than those fed unground milo. Grinding of milo, either as threshed grain or in heads, was conducive to efficient feed utilization. The higher sale prices of the steers fed ground milo more than offset the cost of grinding and showed this to be a profitable method of preparing the grain for cattle. It decreased materially, however, the gains of hogs following the cattle in the feed lots.

Threshing of milo heads increased the gains of steers to a degree statistically significant but not sufficient to justify the expense of threshing. Differences in efficiency of feed utilization by steers due to threshing were not significant. Feed costs per steer and per 100 pounds of gain were higher with threshed than with unthreshed grain. Furthermore, there was no significant increase due to threshing in gains of hogs following the cattle nor in sale price of the steers.

These experiments showed conclusively that the grinding of milo, whether in the form of milo heads or of threshed grain, is to be recommended for fattening young steers, whether or not hogs are placed in the feed lots to follow the steers. They also showed that the threshing of milo heads for use in steer fattening is an added expense offset neither by significantly greater steer gains nor by net returns.

In the beet-growing sections, beet pulp is being used rather extensively for cattle fattening, particularly in the wet form available in close proximity to the sugar factories. There are indications of phosphorus deficiency in beet-pulp and hay rations. Osland (*884*) in a series of experiments over a 5-year period reports that each ton of wet beet pulp replaced 144.03 pounds of grain, 11.06 pounds of cottonseed cake, and 331.93 pounds of alfalfa, when fed to feeder calves weighing approximately 400 pounds. Maynard, Greaves, and Smith (*767*) found that when a fattening ration for cattle consisting of wet beet pulp, beet molasses, alfalfa hay, and salt is supplemented with steamed bonemeal, cottonseed cake, and mill-run bran, which contain phosphorus, pica (perverted appetite due to phosphorus deficiency) was eliminated, the appetite improved, and gains were increased, while feed cost per unit of gain was reduced significantly. Steamed bonemeal proved most efficient in correcting the phosphorus deficiency.

Molasses, particularly blackstrap (cane molasses), has been used extensively in the manufactured or commercial livestock feeds for years, but as a feed by itself it did not come into prominence in cattle-fattening rations until recent years. Its greatest use by cattlemen has been in making unpalatable roughages palatable by spraying or sprinkling diluted molasses on the feed. Some experimenters have reported good results, while as many others have found the opposite. Experiments at the Iberia Livestock Experiment Farm in Louisiana (*939*) showed that the addition of 2.3 pounds of molasses to a ration of 6.5 pounds of cottonseed meal and silage fed ad libitum decreased the gains of 2-year-old steers and increased feed requirements and costs.

Snell,[9] in experiments over a 2-year period in which molasses was fed in conjunction with corn, cottonseed meal, and hay with and without silage to fattening steer calves, found that the addition of molasses increased the consumption of hay and silage but did not increase gains materially. The molasses-hay steers made more efficient use of molasses than did the molasses-silage group, as 100 pounds of corn were equivalent to 112 pounds of molasses and 36 pounds of hay in one case, and to 114 pounds of molasses, 46 pounds of hay, and 68 pounds of silage in the other.

Edwards and Massey (*309*) in an experiment in which molasses replaced one-fourth and one-half of the corn, respectively, in rations for fattening yearling steers, found that molasses was not an economical substitute for shelled yellow corn. However, differences in results with the all-corn and the three-fourths corn and one-fourth molasses rations were not statistically significant. This experiment and others indicate that less than 3.5 pounds per head daily is more satisfactory than larger quantities for fattening steers.

The most widely used steer-fattening ration in the Cotton Belt is one of cottonseed meal and hulls. Great numbers of steers are fattened on these products at the cottonseed-oil mills. The tendency is to feed them to the lower grades of yearlings and 2-year-old cattle, as this combination of feeds is not so suitable for calves, which require longer feeding periods. For many years when cattle were fed heavily on these feeds alone for long periods, they would often become blind and have a staggering gait. This trouble was usually termed "cottonseed meal poisoning." In late years it has been found that the trouble was vitamin A deficiency. A cottonseed meal and hull ration can be materially improved by the addition of some grain or molasses and leafy, green legume hay to supply carbohydrates and carotene, respectively. Rations low in carotene are responsible for vitamin A deficiencies, the first symptom of which is usually night blindness.

At the Texas Agricultural Experiment Station (*595, pp. 5–20*) it was found that a cottonseed meal and hull ration could be greatly improved by the addition of corn. The Texas experiments indicated that cottonseed meal and hulls should not be full-fed for periods of more than 90 to 100 days.

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[9] SNELL, M. G. BLACK STRAP MOLASSES AS A FEED FOR FATTENING STEERS AND FARM WORK MULES. La. Univ. Cir., 7 pp. 1933. [Mimeographed.]

Stanley (*1096*) found in experiments in Arizona that corn silage when fed with cottonseed meal gave larger and more uniform daily gain than did a ration of cottonseed meal and hulls. Gains of 2-year-old steers fed cottonseed meal and hulls were satisfactory for the first 60 to 80 days, but after that diminished rapidly. In the same series of experiments 100 pounds of cottonseed meal were found to equal 170 pounds of whole cottonseed.

In the fattening of cattle in the dry lot it may be stated as a general rule that 50 bushels of good-quality corn and one-half ton of choice-quality legume hay will fatten a good-quality feeder steer of beef breeding in thrifty condition, regardless of its age. It will naturally take the younger animals a longer time to consume this feed and reach approximately the same degree of finish. If these feeds are not available, their equivalents in other feeds can be estimated rather closely. For instance, good silage should replace good hay at about the rate of 3 pounds of silage to 1 pound of hay. Grain can likewise be replaced with beet pulp, molasses, and cottonseed meal and hulls to a certain extent.

Table 2 (p. 564) gives suggested average rations for various classes of beef and dual-purpose cattle.

DUAL-PURPOSE CATTLE

Many farmers, in the Central, Western, and Eastern United States especially, are neither characteristically dairymen nor strictly beef producers. They have found by experience that at one time it may be desirable to produce beef, while at other times the selling of dairy products may be preferable. This situation has brought about the raising of calves and the handling of the breeding herd as dual-purpose cattle.

Unless very high milk production is desired good pastures may be depended on to produce most of the milk in such herds. A new feeding practice suggested for dairy cows producing 4-percent milk is to feed about 0.45 pound of grain daily for each pound of milk produced above 14 pounds (*1268*). When dual-purpose cows not on pasture are fed all the silage and good- to choice-quality hay they will eat, the feeding of grain could well be limited to those producing more than 14 pounds of milk per day.

In those sections where the farmer is neither a beef nor a dairy specialist, he is interested in a cow that will produce a calf of acceptable beef conformation and at the same time produce sufficient milk to raise two calves or to justify hand milking. A 3-year study by the Federal Trade Commission (*229, pp. 11–38*) indicated that the keeping of cattle for both beef and milk production was adaptable to the more intensive types of farming. The results also indicated that profits obtained from the raising of calves on Corn Belt farms were comparatively small. However, these facts must be taken into consideration: (1) Good returns were obtained for a large quantity of roughage which, had it not been utilized for livestock, would have been wasted; (2) a home market was provided for salable crops; (3) on many farms a large acreage suitable only for pasture was made use of; (4)

profitable employment was provided for a season of the year when labor otherwise might be idle; (5) a return was obtained for capital invested in equipment which otherwise in many instances would return nothing.

Perhaps the most practical method of handling a dual-purpose herd where both beef and milk are desired is to follow a system that fits into the plan of operating the farm. If fat calves are to be produced a satisfactory method of growing and developing calves is to feed them grain while they are nursing. The calves should be started on grain as soon as possible, or at 3 to 4 weeks old. If the breeder proposes to carry his calf crop over and market them as long yearlings or 2-year-olds, however, the feeding of grain to suckling calves is not believed to be profitable, unless the cows and calves have poor pasture.

The spring calf crop may be marketed when weaned in September or October as feeders or as fat calves if creep-fed, or they may be fed a full grain ration and finished as fat calves after weaning. Calves dropped early in the year may be marketed the following summer as fat yearlings 15 to 16 months of age, when they should weigh 850 to 900 pounds if wintered well and fattened on grass with a grain supplement.

The methods to be employed in the development of dual-purpose calves as feeders or fat cattle are the same as discussed for strictly beef calves. There should not be a significant difference in the fattening of strictly beef-bred calves and dual-purpose-bred calves as regards rate and efficiency of gain. Dual-purpose calves, however, have a tendency to grow instead of fatten, and accordingly require a greater length of time to attain the same degree of finish.

TABLE 2.—*Suggested average daily rations for various classes of beef and dual-purpose cattle*

Class of cattle	Corn[1]	Grain sorghums	Barley[1]	Oats	Molasses (cane or beet)	Cottonseed meal or cake[2]	Linseed meal or cake[2]	Wheat bran	Silage (corn or sorghum)	Beet pulp (wet)	Legume hay	Mixed hay	Grass hay	Straw (cereal) or stover	Cottonseed hulls	Winter pasture or range	Summer pasture or range
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Wintering breeding cows									30		8						
						1.5			25					10			
	2			2				2				10		10			
										40	5			10			
						1.5										X	
Wintering yearling heifers											20						
						1			15			10					
	2			1			1	1					12				
			3			1			10		5			5		X	
		4				1							4		10		
Wintering calves											13						
									10		10						
	1			1				1				10					
							1				8			4			
Wintering yearling steers							1			20				5			
		4											8	4			
						1			16					4			
						1										X	
						1			15						15		
Wintering bulls—1,000 pounds weight	3			2			1					20					
		6											5			X	
			5				1		20			3					
Fattening on grass:																	
Creep-feeding calves	4			2													X
	4					1											X
2-year-old steers	8					1											X
			10														X
Fattening in dry lot:[3]																	
1,000-pound steers	20										10						
	17				3	3			15				3				
			20			2.50						10					
		18				3			15				3				
	16					3			25			5					

800-pound steers	18										9						
		15				3									15		
			4		3					50	10						
			15				2		15				3				
		15			2.5	2									20		
600-pound steers	16										7						
					2.5					40	8						
	12					2			9			4					
		12				2			15								
		12				2.5						4			15		
400-pound calves		12				2			14					2			
	10					2						5					
			10		2		2		10				3				
			12				1				5						

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[1] Corn and barley may be replaced wholly or partly by such feeds as wheat, rye, or rice products; however, these feeds are usually not so palatable and are slightly less efficient than corn and barley, pound for pound.

[2] Cottonseed and linseed products may be substituted for with soybean, velvetbean, and peanut products.

[3] The rations for dry-lot fattening should be considered as average quantities of feed per head per day for the entire fattening period. Accordingly, the ration for a 1,000-pound steer as given would be for a steer weighing nearer 1,100 pounds.

THE FEEDING OF DAIRY COWS FOR INTENSIVE MILK PRODUCTION IN PRACTICE

by Edward B. Meigs[1]

HERE are the main considerations involved in modern dairy cattle feeding. The author shows the relative importance of roughage and concentrates and proper ways of feeding them, tells how to determine the amount of food required. and outlines a satisfactory procedure. based on lengthy experience. for the feeding of dairy cows. He ends with a discussion of the requirements of the mature animal for various nutrients and some warning advice against overenthusiasm in certain directions.

In attempting to give any kind of general advice in regard to the feeding and treatment of dairy cows, one is embarrassed by the immense extent and complexity of the subject.[2] The cows themselves vary from the scrub animal that is with difficulty induced to give 2,000 or 3,000 pounds of milk in a year to the high-bred modern cow, which will yield 20,000 or 30,000 pounds in the same period and will use up her own body if her food is insufficient to support this enormous production. Animals showing this wide variation are kept on farms that may be remote from cities, with unlimited pasture land and small facilities for importing manufactured concentrates; or they may be in expensive suburban districts where the cost of land is high and centers for the distribution of manufactured foods are close at hand.

To meet the problems created by all these different situations, knowledge is still very inadequate. It has appeared in the last few years that animals suffer from numerous diseases due to the lack of certain mysterious chemical compounds, which are present in normal foods in very small quantities and the existence of which was not even suspected until a few years ago. But such diseases often do not appear until after the deficient foods have been fed for several months or years, and therefore a great many of the old views regarding food which were based on short experiments must now be discarded. Many of the foods used in farm rations have not been studied at all from the point of view of the new discoveries.

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[1] Edward B. Meigs is Chief of the Division of Nutrition and Physiology, Bureau of Dairy Industry.

[2] No one should write on the nutrition of farm animals at present without acknowledging that there are several recent, comprehensive, and admirable works on the subject. The latest edition of Morrison's Feeds and Feeding (*819*) [3] was published in 1936. It contains a full and illuminating discussion from the practical point of view, with numerous references to the literature. Students who have had some training in physiology and biological chemistry may be referred to Maynard's Animal Nutrition (*769*) published in 1937, which also contains an illuminating comprehensive discussion and numerous references. A very full discussion of the mineral nutrition of farm animals was published by Mitchell and McClure (*803*) in 1937. Finally, a general book on the vitamins was published by Sherman and Smith (*1055*) in 1931, and the very voluminous recent literature on this subject is discussed in articles on vitamins in the Annual Review of Biochemistry (*283, 339, 479, 721, 912, 913, 1041*). The present article attempts to give only a brief discussion of some of the practical aspects of feeding dairy cows, and the writer's views are based partly on personal experience in connection with experimental work at the Beltsville, Md., station of the Department of Agriculture and partly on the much fuller expositions of physiological and nutritional principles given in the works above mentioned.

[3] Italic numbers in parentheses refer to Literature Cited, p. 1075.

In spite of these difficulties and many others, dairy cows must be fed. But it must be clearly understood that the advice which can be given on the subject at present cannot be exhaustive and final. It can cover only certain parts of the situation to be met, and must be based largely on judgments and inferences which have not yet been fully tested out.

The bovine species has been nourishing itself on pasture for countless ages, but to determine how it has done so is difficult or impossible. It seems quite likely that these animals are fitted to select from the great variety of plants to be found in any field those which will keep them in good health and enable them to secrete enough milk to support their offspring. The problems with which we can most legitimately concern ourselves arise when cows are bred to produce much more milk than their offspring require and are kept in barns and fed exclusively on foods selected by their human masters, many of which are more concentrated than and quite different from those which they could obtain under natural conditions. In the following discussion, therefore, the problem considered will be that of the modern dairy cow, bred and kept for intensive milk production. It may be more specifically described as that of keeping a herd of modern high-producing cows in good health and near maximum fertility and milk yield[4] through an unlimited number of generations.

The dairy heifer is bred before she has attained her full growth, and from the moment of her first conception to the end of her useful life, she is always either carrying a calf or lactating or both. The intensively bred modern cow cannot eat enough during the first month or so of lactation to provide the material required for her milk, and during this period material from her body is used in the milk-production process. These losses of body substance are made up during other parts of the reproductive cycle. In view of this situation, the feeding of dairy cows cannot be divided, from the practical point of view, into periods of feeding for maintenance, growth, gestation, and milk secretion. The cows must be fed more than they require in the less active portions of the reproductive cycle in order to make up for unavoidable losses in the more active portions.

Much knowledge regarding the importance of purified chemical compounds in nutrition has come from experiments with rats. But the use of purified chemical compounds is expensive, even with small animals, and experiments with such compounds are, therefore, not continued for any great length of time. We are still far from knowing what chemical compounds would be necessary and in what quantities to maintain a colony of rats in a high condition of fertility through several generations. And even if we had such knowledge for rats, it could not be applied without great reserve to other species of animals.

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[4] "Near maximum milk yield" means within, say, 5 or 10 percent of maximum. The problem of keeping cows actually at maximum milk yield for long periods has never been studied, but it would probably involve feeding large surpluses of expensive foods which could not be paid for by the extra milk obtained.

It is not economically possible to carry out long-continued experiments with chemically purified compounds on large animals like dairy cows, but there is no difficulty about studying the effects of the ordinary farm feeds on growth, reproduction, and lactation in these animals. Such experiments have been carried out in vast numbers in the past; but in many of them only one function of the animal, as for instance milk secretion, was taken into account, and many have not lasted long enough to show whether the rations used were capable of maintaining the cows at a high level of milk secretion and in good health and fertility throughout their lives. In the following discussion of the practical aspects of feeding dairy cows, such long-continued experiments as are on record have been given much consideration.

RELATIVE IMPORTANCE OF ROUGHAGE AND CONCENTRATES AND PROPER WAYS OF FEEDING THEM

A cow's food consists of concentrates and roughage. The concentrates, as their name implies, are foods in which the nutritive energy is high in proportion to their weight and bulk; they are from 75- to 100-percent digestible. In roughages, the nutritive energy is lower in proportion to weight, the digestibility being from 30 to 75 percent. The concentrates consist of grains and highly digestible materials manufactured from grains, while roughages are whole plants, with the exception of the roots, often made into hay by drying. Pasture and silage also are usually included under the head of roughage.

In numerous experiments with cattle, the nutritive properties of grain and hay have been studied by feeding each kind of food without the other over long periods. Cattle cannot be kept alive for more than a year or so on grain alone, but they may remain alive and in good health for many years on hay alone. High-producing cows, however, cannot be kept anywhere near their maximum milk production on hay alone, because they are not able to eat and digest the enormous bulk of this kind of food which would be necessary to supply the nutritive energy required for heavy milk production.

In order to keep high-producing cows in good health and near maximum milk production, therefore, it is necessary to feed both hay and grain—the hay to provide some nutritive energy, but more particularly certain nutritive essentials necessary to keep animals in good health; the grain to provide a large amount of nutritive energy in such concentrated form that the cows can consume and digest enough of it for heavy milk production.

Nutritive energy is that part of the energy of the food which can undergo chemical changes within the body and thus supply the energy necessary to keep animals warm, to enable them to move about, and to make possible certain chemical changes within the body. The nutritive energy of any food can be measured and compared with that of any other food, and may be designated simply as its energy value. It would perhaps be better to describe the parts played by grain and hay in the nutrition of dairy cattle by saying that the chief function of hay is to supply certain chemical compounds required to keep animals alive and in good health, and that the chief function of grain is to supply the large amount of concentrated energy required for heavy milk secretion.

Cows can be kept for many years in good health and near maximum milk production on rations of grain and hay alone without pasture or other green or succulent food. In order to do this, however, it is necessary to pay particular attention to the kind of hay fed. Hay varies greatly in the quantity of various important chemical compounds that it contains.

If it were necessary to get along with only one kind of hay, it would be much better to use legume hay than grass hay. Legume hay contains more of almost every chemical compound necessary for nutrition than does grass hay. But experience has shown that cows will not eat as much hay or thrive as well on either legume hay or grass hay alone as they will on a combination of the two. The roughage of the dairy ration may, therefore, consist of about equal parts of legume hay and grass hay. The best known chemically and probably the best of the legume hays is alfalfa. Among the grass hays, timothy has been much studied and may be taken as an example of the kind of grass hay to be fed. Other roughage which, like timothy, is high in carbohydrate and low in protein may be substituted, as for instance corn silage. In this case, of course, about equal amounts of legume hay and of the dry matter of corn silage should be fed.

The vitamins are contained in much larger quantity in hay of good quality than in hay of poor quality. It is important, therefore, to supply cows with hay of good quality, and this can be done by using hay of the U. S. No. 1 grade. For some years the Bureau of Agricultural Economics has been engaged in the task of grading various kinds of hay. Descriptions of the different grades are to be found in the Handbook of Official Hay Standards (*1155*), and agents of the Bureau of Agricultural Economics are stationed in various parts of the United States for the purpose of grading hay that is put on the market. It is a disadvantage in using silage that no system has yet been devised of judging the quality of this food from its appearance, although silage, like hay, varies greatly in quality.

Since the vitamin content of hay is so important for dairy cows and it is not always easy to obtain hay of the highest quality, it is not only economically advantageous but also good for the health of the cows to induce them to eat as much hay as possible. This can be accomplished not only by feeding a mixture of legume hay with either grass hay or some other low-protein roughage such as corn silage, but also by feeding the cows at all times as much hay as they will eat, and keeping the grain down to a point where they will be hungry enough to clean up quickly all that is given to them. This excellent practice is applied by all experienced dairy farmers.

For cows that are not on pasture, then, the basic portion of the dairy ration is as much roughage of good quality as they will eat, at least a third of the dry matter of this roughage consisting of legume hay. But good dairy cows will not eat enough roughage to supply the total digestible nutrients required for maximum milk production, so it is necessary to add concentrates to the ration. Even when this is done, most good dairy cows do not consume enough nutrients to cover the requirement for milk secretion in the early part of the lactation period and lose weight for the first few weeks after calving. The problem of how much to feed at this period resolves itself into giving as much roughage as they will eat at all times, and as much concentrated feed as they will clean up in the first half hour after it is put in the manger.

After the cow has become accustomed to lactation, however, and the milk yield has declined somewhat, a period is reached where she will eat more than enough roughage and concentrates to cover her requirement and will begin to gain weight unless the food supply is restricted. Numerous studies have been made to determine how much food should be given to maintain maximum milk secretion without waste during this part of the lactation period.

DETERMINING THE AMOUNT OF FOOD REQUIRED

The total-digestible-nutrient or energy content of many farm feeds has been determined, and the figures obtained have been compiled in tables published in Morrison's Feeds and Feeding (*819, p. 954*). Morrison's tables give not only the total digestible nutrients of the feeds, but also their content of a number of chemical constituents, as for instance protein, fat, phosphorus, etc. The requirements of cows are better known for some of these constituents of foods than for others.

The requirement for total digestible nutrients has been much studied, and there is some approach to agreement among different investigators concerning it. In devising rations for dairy cows, the usual practice is to select one which contains in liberal quantities all of the chemical constituents known to be necessary for the nutrition of these animals, and then to feed to each cow enough of the ration to supply the total digestible nutrients that she requires according to her body weight and her milk and fat yield. The energy requirements of cows of various body weights and at various levels of milk and fat yield have been determined in experiments in which cows have been fed for long periods on such quantities of good dairy rations as would keep them at uniform body weight. The quantities of energy or total digestible nutrients in the rations found necessary to maintain uniform body weight are then calculated, and from the results obtained the energy requirements for various body weights and various milk and fat yields are calculated and compiled in tables. The quantities of protein and total digestible nutrients given by Savage (*1011*) as required daily by cows for maintenance[5] and milk and fat yield[6] are given in table 1. By using these figures in conjunction with those given by Morrison for the total digestible nutrients contained in dairy feeds, the amounts of various rations required by any cow, according to Savage, can be calculated. There is good reason to believe that the Savage standard for energy requirement is not far from giving the quantities of nutritive energy necessary to keep good dairy cows near maximum milk production, and it will be used as a basis for the procedure recommended in this article.

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[5] As stated in table 1, the maintenance allowance may be increased or decreased in proportion to body weight for practical purposes. For very large or very small animals, the change in maintenance allowance should be somewhat less than in proportion to body weight, the mathematical formula used in calculating this change being $X=M\left(\frac{W}{1000}\right)^e$. X here is the maintenance requirement to be determined; M, the maintenance requirement of a 1,000-pound cow; W, the body weight in pounds of the cow whose requirement is to be determined; and e, an exponent in regard to the value of which investigators are not agreed, the values assigned varying from 0.63 to 0.87.

[6] The Savage standard is used as the basis of the discussion in this article, partly because it was used as the basis in the experiments to be described later and partly because it is the most liberal of the feeding standards It is true that several less liberal standards have since been published, and that Savage himself has suggested a less liberal scale of feeding than his original standard. The writer, however, is of the opinion that, where milk production near the maximum is desired, it is advisable to feed at least as much protein and total digestible nutrients as are recommended in Savage's original standard. The reasons for this view are discussed in the proper place in the text.

TABLE 1.—*The Savage standard of daily food requirements of dairy cows for maintenance and milk production*

Item	Digestible crude protein	Total digestible nutrients
	Pounds	*Pounds*
For mainetance of cow weighing 1,000 pounds [1]	0.700	7.925
Additional allowance for each pound of milk containing the following percent of fat:		
2.5	.053	.257
3.0	.057	.287
3.5	.061	.319
4.0	.065	.350
Additional allowance for each pound of milk containing the following percent of fat:		
4.5	0.069	0.379
5.0	.073	.405
5.5	.077	431
6.0	.081	.457
6.5	.085	.484
7.0	.089	.508

[1] For cows weighing more or less than 1,000 pounds, it is sufficiently accurate for practical purposes to increase or decrease the maintenance allowance in proportion to the body weight.

A concentrate mixture containing liberal quantities of protein, fat, and phosphorus may be made up by mixing four parts of corn meal and three parts of wheat bran with three parts of one or more of the oil meals. To this should be added 1 percent of salt. It is well known that cows must have salt as a part of their ration, and it is good practice to supply this, not only by adding this amount to the grain mixture, but also by providing a box of salt in the yard or in the pasture field, so that the cows can consume as much as they wish in addition.

A SATISFACTORY PROCEDURE FOR THE FEEDING AND CARE OF DAIRY COWS

The feeding procedure just outlined is one by which cows have been kept through one generation, without pasture or other green or succulent feed, in a normal condition of health and fertility and near maximum milk production for periods of 4 to 9 years in actual experiments. These experiments were carried out by the writer and collaborators with a herd of 20 to 30 cows at the experiment station of the Bureau of Dairy Industry at Beltsville, Md. The procedure will now be specifically and fully described.

The rations consisted of hay combined with a concentrate mixture. The hay was either U. S. No. 1 alfalfa or about half and half U. S. No. 1 alfalfa and U. S. No. 1 timothy.[7] The milking cows were offered at all times as much hay as they would eat. The concentrate mixture contained usually 4 parts of corn meal, 3 parts of wheat bran, 2 parts of cottonseed meal, 1 part of linseed meal,[8] and 1 percent of salt. It was impossible to keep the cows from losing weight in the early part of the lactation periods, although they were fed not only as much hay as they would eat, but also as much of the concentrates as they would clean up in half an hour after they were fed. In the later parts of the lactation period the cows were allowed to gain back as much body weight as they had lost at the beginning. After that they were still fed as much hay as they would eat and sufficient concentrates to bring their consumption of total digestible nutrients up to what they required according to the Savage standard.

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[7] Corn silage was sometimes substituted for the U. S. No. 1 timothy hay.

[8] The oil meals were not extracted with fat solvents but by the old process.

In their dry periods the cows were fed 20 percent more total digestible nutrients than they required according to the Savage standard. When the hay was alfalfa alone, they consumed about equal quantities of grain and hay; when it consisted of a combination of alfalfa and timothy, they consumed about half again as much total hay as they did grain.

The cows were bred as nearly as possible 6 months after they calved. If they became pregnant on the first breeding, they were continued in milk for the first 12 complete calendar months after calving, and then had a dry period of about 3 months before calving again. If there was delay in conception, the cows were kept in milk long enough to make the milking period four times as long as the dry period.

The cows were kept in stanchions and milked three times a day by hand. They were turned out for a part of each day in a fenced lot in which no grass grew. The time spent in the lot varied from a few minutes daily when the weather conditions were very bad to 16 hours daily when the weather was most favorable.

The results of this procedure were found satisfactory for the first generation of cows subjected to it (fig. 1). But the heifers in the second generation subjected to such procedure were found difficult to get with calf. They came in heat regularly, but failed to become pregnant even though bred many times. Heifers from cows that had the same barn rations as those described above but with even small amounts of pasture occasionally in the summer were not difficult to get with calf; and the failure to conceive in heifers from cows that had had no pasture tended to be corrected if the heifers themselves were given pasture for fairly long periods.

Pasture should, therefore, be made a part of the annual dairy ration. It is important not only because it helps to keep cows in a state of high fertility, but also, as will be shown later, because it contains large quantities of vitamin A which can be stored in the cows' bodies and thus protect them from the effects of deficiencies of this vitamin that might occur in the winter through the feeding of roughage not of the best quality. There is every reason to think that good pasture is rich not only in vitamin A but also in other organic nutritive essentials that have not been much studied up to the present time, and that turning cows out on pasture for a part of the year provides insurance against a number of deficiencies that cannot be avoided by any kind of barn rations known at present.

In most cases pasture is not only a means of insurance against sterility and deficiency diseases; it is also economically advantageous. Farmers naturally turn their cows out on pasture for about 6 months every year. It should be kept in mind, however, that, unless the pasture is plentiful and of unusually good quality, high-producing

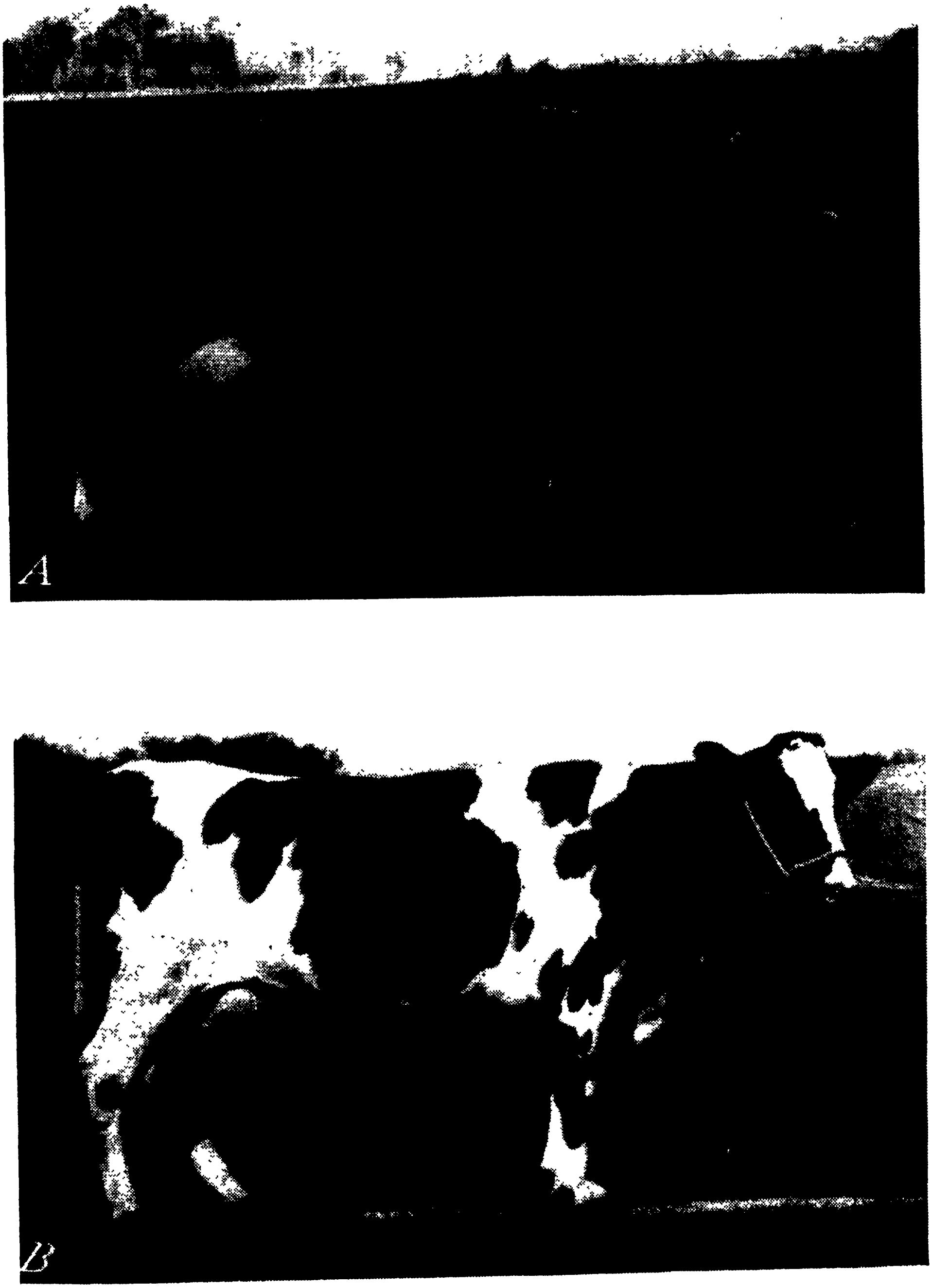

Figure 1.—Long-time feeding without pasture was satisfactory for one generation of cows. *A*, This cow gave an average of 7,391 pounds of milk a year for nearly 9 years on a ration of grain and a mixture of alfalfa and timothy hay. *B*, Grain, late-cut U. S. No. 3 timothy hay, and 20 pounds daily of yellow carrots enabled this cow to give an average of more than 10,000 pounds of milk a year for 4 years.

cows cannot consume enough of it to support their milk yield, and grain must be fed in addition to keep this function near its maximum. The cows that were given the barn rations described above through the winter did not increase in milk yield when turned out on pasture in the spring, even though grain feeding was continued all through the pasture season.

Under certain circumstances, as near cities where land is very expensive or where high records are the chief consideration, pasture adds little or nothing to the economy of feeding cows, and it is convenient to reduce it as far as possible. There are no experiments to show how far pasture can be reduced without affecting the fertility of dairy cows, but there is strong evidence for the view that rations such as those described above are nearly complete without pasture. It may be supposed for the present, therefore, that if cows are turned out on good pasture for 2 months every year and fed at other times as described above, the rations will be sufficient to support the herd permanently.

It has not been possible to keep many of the cows available for experimental purposes for many years under the procedure which has just been described either with or without pasture, partly because a large proportion of the herd was needed for experiments with less satisfactory rations, and partly because every herd of cows is subject in the course of years to such accidents as epidemics of positive reactions to tuberculosis or contagious abortion. In spite of such restrictions and accidents, satisfactory evidence was obtained which showed that cows were likely to remain in good health under such treatment either with or without pasture, to reproduce normally for one generation, and to yield liberal quantities of milk up to the age of 12 or 13 years. About 90 percent of normal calves were obtained, and it required less than two breedings on the average to produce pregnancy.

The annual milk and fat yields are calculated by dividing the total yields for the periods under consideration by the total time in years from the time of first calving in the period to the end of the last dry period, and including all the intervening dry periods. There were two Holstein-Friesian cows and four Jerseys whose records while fed and treated as outlined above happened to extend to periods of nearly 4 to over 10 years. In spite of the long dry periods allowed (25 percent of the periods in milk), the Jersey cows yielded 4,613 to 6,921 pounds of milk and 291 to 388 pounds of fat annually on the above basis, and the Holsteins, 13,644 to 15,098 pounds of milk and 409 to 441 pounds of fat. The periods for the two Holstein cows were close to 4.3 years each on barn feeding alone, and they averaged 14,371 pounds of milk and 425 pounds of fat annually in those periods.

In the case of the four Jersey cows, the total periods on the feeding and treatment in question included periods on pasture and corn silage. The total periods ranged from 3.92 to 10.30 years, with an average of 7.23 years, and the cows gave 5,776 pounds of milk and 332 of fat annually on the average. Three of them were on rations of grain and hay alone, without pasture or succulent feed, for continuous periods ranging from 4.60 to 8.76 years, averaging 6.51. The fourth cow is omitted from this calculation because she was on dry feeds for a short time only. The three cows during the periods mentioned gave an average of 6,374 pounds of milk and 360 of fat annually. The milk and fat yields were larger on the dry feeds partly because the periods on pasture included the first lactations, in which the yield is normally smaller, and partly because the fourth cow happened to be a low producer.

That the barn rations fed to these cows were well suited to maintain liberal milk yields for long periods is shown by the way in which the milk yields were sustained in all cases. Both of the Holstein cows gave their largest milk yields in the last lactations in the periods studied at ages of over 5 years. The Jersey cows gave their largest yields at the ages of 5, 6, 6, and 8 years, respectively, and had decreased less than 10 percent below their highest yields at the ages of 6, 7, 9, and 10 years. One of these cows had been on barn rations composed exclusively of dried feeds for more than 4 years in succession when she gave her highest yield.

In actual practice, the cows ate about 10 percent more total digestible nutrients than they required according to the Savage standard during periods when they were not on pasture. They remained in very good condition, but were not extremely fat.

If cows are fed and treated as just described, they will receive more protein, fat, vitamin A, calcium, and phosphorus than has been found to be the minimum requirement of these constituents in the experiments bearing on the subject. These are the constituents of farm rations that have been most studied up to the present time, and much information has been accumulated bearing on the quantities required by dairy cows and on the effects of a shortage of any one of them on the health and performance of the cows. It is known that a shortage of one of these constituents will have unfavorable effects on either health or milk yield, and it seems likely, therefore, that it will be good practice to feed somewhat more than the minimum requirement of each in the case of a herd of good cows that is being maintained for intensive milk production. Knowledge, however, is not yet sufficiently precise to make it possible to say just how cows ought to be fed in order to produce the best results with the highest economy. The procedure outlined has given satisfactory results in actual practice and may be regarded as at least an approximation of good feeding. The following discussion of the work on the requirements of cows for the dietary constituents under consideration will throw light on the questions as to how the requirements may be supplied from other foods than those suggested, how far the rather liberal quantities allowed in the procedure outlined may be reduced with safety, and what the results are likely to be if they are reduced too far.

ENERGY REQUIREMENTS

The total digestible nutrients of a ration represent fairly closely its content of metabolizable energy. This is the total quantity of energy that can be obtained from the chemical transformations undergone by food within the animal body. It is to be hoped that tables of metabolizable-energy values will be compiled and published in the not distant future. In the meantime the tables for total digestible nutrients are the most accurate representation available of metabolizable energy, and in the following discussion the two terms will be used as being sufficiently interchangeable for practical purposes. The question of net energy[9] will be discussed only very briefly, and the metabolizable energy of food will frequently be spoken of simply as its energy content.

The energy requirement of dairy cows and other farm animals has been much studied in the past—partly in rather brief balance experiments, in which the energy contained in the food has been compared with that given out as heat and in the milk and excreta; and partly in longer experiments in which the quantity of food energy required to maintain milking cows at uniform body weight has been determined. The balance experiments have shown that cows can often secrete milk more economically than is indicated by the results of the body-weight experiments, but there are many strong reasons for thinking that the results of the latter experiments should be accepted as a guide in practice rather than those of the former. These reasons may be outlined as follows:

A cow responds to the demand that she secrete milk economically by reducing the rate of milk yield faster than she would under more liberal feeding. In the balance experiments, the economy of milk yield is determined by comparing the energy intake in the food, over and above what is required for maintenance, with the energy output in the milk. From this point of view, if a cow consumed exactly her theoretical requirement she might be secreting milk very economically in the physiological sense, and yet this might be very wasteful as far as the farmer was concerned.

The following example will illustrate the situation concretely. Suppose there are two cows, A and B, each of which requires 8 pounds of total digestible nutrients for maintenance. Cow A is yielding 40 pounds of 4-percent milk daily, and cow B, 20 pounds of 4-percent milk. According to the Savage standard, cow A will require 14 pounds of total digestible nutrients daily to cover her milk yield, which, added to the 8 pounds for maintenance, will amount to 22 pounds altogether. Cow B requires 8 pounds of nutrients for maintenance, and 7 pounds for milk yield, or 15 pounds altogether. Suppose cow B is consuming exactly her requirement, while cow A is consuming 20 percent more than her requirement, or 26.4 pounds of nutrients daily. In the physiological sense, then, cow B is secreting milk much more economically than cow A. But from the farmer's point of view cow B is consuming 15 pounds of nutrients in order to produce 20 pounds of milk, or 0.75 pound of nutrients per pound of milk, while cow A is consuming 26.4 pounds of nutrients to produce 40 pounds of milk, or only 0.66 pound of nutrients per pound of milk, and is, therefore, decidedly the more economical producer of the two.

In the most recent edition of Morrison's textbook (*819*), two standards of total digestible nutrients are given for milking cows, one more liberal than the other. In discussing these standards, Morrison states that it is often more economical to feed less total digestible nutrients than are required for maximum milk production, because cows cannot be maintained at maximum production without large amounts of concentrates, and in many areas of the country roughage is so much cheaper than concentrates that the extra amount of milk obtained by feeding the extra concentrates is not sufficient to pay for them. Morrison recommends that the higher amounts of total digestible nutrients be fed to good cows under usual conditions, but says that it may be more profitable to feed according to the lower figures when roughage is very cheap in comparison with concentrates.

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[9] Some years ago the view was put forward that stock feeders should be furnished with tables of "net energy values" for farm foods, which should represent the fractions of the metabolizable energy of the foods that could be used by animals to produce some product useful to the farmer, such as fat. The metabolizable energy of hay or corn cannot be converted by a steer completely into the metabolizable energy of body fat. A certain proportion of the food energy is always converted by the animal into heat, and several investigators have supposed that the fractions converted into heat and fat, respectively, would be sufficiently constant to be used in tables of food values. Morrison (*819*) has given a table of net energy values and discussed the subject with references to the literature. Most recent investigators, including the writer, however, think that the "net energy values" of individual foods are not sufficiently constant to be used as a basis in practical feeding.

Morrison's more liberal standard recommends, on the average, about 7 percent less total digestible nutrients per pound of milk than the Savage standard, and experiments have indicated that even the Savage standard does not provide quite enough total digestible nutrients to keep cows near maximum milk production. There are no experiments to show what effect it would have on the milk production of good dairy cows to keep them for several years on rations that do not supply enough total digestible nutrients to maintain milk production near its maximum.

Experiments carried out in Minnesota, in Missouri, and in the Bureau of Dairy Industry Station at Beltsville, indicate that cows are kept close to maximum milk secretion when they are fed good rations containing the quantities of total digestible nutrients recommended by the Savage standard or 5 to 10 percent more, and that Jersey cows so fed will often go on secreting about 6,000 pounds of milk yearly for several successive lactation periods. In Holsteins, the milk yields obtained have been about 14,000 pounds annually. In both breeds the rate of decline in milk yield has been about 50 percent of the maximum monthly yield in the course of 12 months.

For the reasons already given, it seems likely that yields near the maximum will coincide closely with the most economical yield, in the sense that by getting such yields the farmer will get the largest possible quantity of milk per pound of total digestible nutrients given to his cows. To assign a level of feeding that will give the best results in a strictly financial sense is a very complicated problem. To solve this problem, there must be taken into account, among other things, the varying prices of roughages and concentrates, the overhead expense represented by barn space and labor, as well as by food for maintenance required to keep a larger number of cows to produce a given quantity of milk, and the extra price that can be obtained for calves in some districts if the cows in the herd have good milk records. It would seem that this problem must be left to a large extent to the individual dairy farmer who knows his own particular conditions.

The effects of a moderate reduction in the energy content of the ration below the requirement of milking cows are a decline in milk yield and a loss of body weight. In a few weeks the cow, without becoming sick, reaches a milk yield and body weight that can be supported on the reduced ration and continues under the reduced conditions at a constant body weight. Severe reductions in the energy of the ration result in visible emaciation, but this can often be carried surprisingly far without producing any strictly pathological results. The results of energy deficiency are in marked contrast to those of deficiencies in vitamin A, calcium, phosphorus, and iodine, which often produce pathological symptoms without the changes that are ordinarily attributed to lack of food.

The situation with regard to the energy requirements of dairy cows may be summed up by saying that the figures given as the average requirements by different investigators vary from those given by Savage to figures about 20 percent lower than his. These figures are all based on body weight and balance experiments, and there is very little experimental evidence on the question as to how milk yield is affected by different levels of energy consumption over long periods. To devise experiments that would throw clear light on this question would be a difficult matter, because individual cows vary considerably, not only in their energy requirements for maintenance, but also in their tendency to convert food energy into milk or body fat. From considerable study of such experiments as bear on the question, and from many years' observation of a herd of cows fed at various levels of energy consumption, the writer has formed the opinion that good dairy cows will yield the largest amount of milk per pound of total digestible nutrients consumed over a period of serveral years when fed approximately according to the Savage standard.

In this matter, however, it is both legitimate and desirable for the dairy farmer to experiment to some extent for himself. It will not seriously injure the health of his cows to feed somewhat more or somewhat less nutritive energy than they require for maximum milk yield, and it is important for him to know which of the cows will respond to liberal feeding by large returns in milk. Furthermore, the effects of underfeeding and overfeeding are easily detected by changes in body weight and milk yield. The condition of the cows should be watched and should supplement the figures given in the standards as a guide in feeding. The response in milk yield of the individual cows to liberal feeding should also have great influence in determining the procedure to be followed. Cows in poor condition from long-continued underfeeding will often respond with a surprisingly increased milk yield to liberal feeding for a month or so before they calve. But the figures given in the standards set useful limits to the range within which experimentation is worth while. The dairy farmer can count on it that few cows will respond with profitably increased milk yields to continued feeding much above the Savage standard, and that still fewer will fail to show marked signs of undernutrition and disastrous reductions in milk yield if fed for any length of time 20 percent or more below this standard.

THE MOST IMPORTANT CHEMICAL COMPOUNDS

The number of chemical compounds known to be necessary to keep animals in good health is large. But most of them are needed in very small quantities and are present in natural foods in greater or lesser amounts. In the case of animals fed on natural foods, therefore, deficiencies in most of the compounds necessary for nutrition do not occur; under practical conditions, deficiencies of only a few such compounds have been observed to produce pathological symptoms. The deficiencies known to have produced pathological or unfavorable conditions in dairy cows in practice are those of protein, fat, vitamin A, calcium, phosphorus, and iodine.

THE PROTEIN REQUIREMENT

Although much effort has been devoted to studying the protein requirement of dairy cows, authorities are by no means agreed as to what this requirement is. The quantities of protein recommended by Savage have been given in table 1 (p. 571). Some years previous to the publication of Savage's work, Haecker had published a standard which allowed about 20 percent less protein for each pound of milk than does Savage's standard. In the 1936 edition of Morrison's Feeds and Feeding (*819, p. 1004*) still other figures are given for the protein requirements of dairy cows. According to the Morrison figures, good cows under usual conditions should get about 7 percent less protein for maintenance and about 25 percent less per pound of milk than the Savage standard recommends; and for certain conditions where concentrates are expensive still lower quantities of protein are advised.

The Savage standard allows 0.7 pound of digestible crude protein daily for the maintenance of a 1,000-pound cow, and, in addition, about twice as much protein as is secreted in the milk. Several other investigators have obtained results that suggest that a milking cow weighing 1,000 pounds need receive only 0.5 pound of digestible crude protein for maintenance plus 1.25 times as much protein as is secreted in the milk.

Cary (*196*) studied the effects of feeding these levels of protein on the milk yield of good dairy cows for long periods. The cows were fed 10 percent more total digestible nutrients than required by the Savage standard. The low-protein ration consisted of corn meal, wheat bran, a commercial dextrin preparation. alfalfa hay, and timothy hay. The high-protein ration was the same except that the protein content was raised by substituting for some of the dextrin preparation a quantity of casein with the same total-digestible-nutrient content. Two cows were used in the experiment.

When changed from the high-protein to the low-protein ration at the beginning of the dry period, one cow in the immediately succeeding lactation period produced 50 percent less milk and fat. The other cow maintained her production for nearly 8 months in the first lactation on the low-protein ration, but lost about 100 pounds in body weight. At the end of the 8 months, the milk yield and percentage of fat dropped abruptly. In her next lactation on the low-protein ration, this cow gave only 22 percent of the milk and 15 percent of the fat yielded in the preceding high-protein lactation, and went dry in 5 months. When the cows were put back on the high-protein ration, both immediately resumed their original higher level of milk and fat production.

These results are instructive in showing how cows differ in their response to inadequate protein in the ration. Some reduce their yield immediately; others, not until after several months. In all cases the milk yield and the percentage of fat are finally greatly reduced, though no permanent damage is done to the cow, which recovers in both milk and fat yield as soon as she is put back on an adequate protein ration. The results show that, for the feeds used in this experiment, 0.5 pound of protein for the maintenance of a 1,000-pound cow plus 1.25 times the protein secreted in the milk is not sufficient to maintain maximum milk production.

To determine the quantity of protein required for milk secretion is a very complicated problem. Proteins are made up of combinations of simpler chemical compounds called amino acids (see the article on Protein Requirements of Man, p. 173). Several of these amino acids are called essential because animals cannot manufacture them from other compounds, and, in order to remain in good health and secrete milk, they must obtain these essential amino acids from the protein of the food. Some proteins lack some of the essential amino acids or contain them only in small quantities, and all of the essential ones are required in considerable quantities for the formation of milk protein. Food proteins differ, therefore, in their ability to support milk secretion, according to their amino acid make-up, and it is not possible to say exactly how much protein is required for a given amount of milk without first knowing what kind of protein is to be fed. Strictly speaking, there is no such thing as a general protein requirement for dairy cows.

Further, in the ordinary balance experiment, only the total amount of nitrogen taken in and given out by the cow is determined, and the protein intake and output is calculated from the figures obtained for nitrogen. The fact that an animal is not losing nitrogen from its body, which is taken to indicate that it is getting an adequate amount of protein, does not necessarily show that it is not losing one or more of the essential amino acids. Such loss might be concealed by the storage of a small amount of nitrogen in the form of some other amino acid. The problem of the protein requirement for milk secretion, therefore, is still far from being solved with any exactness. In view of these and many other results (*774, pp. 207, 210*) tending to show that liberal feeding of protein is necessary for high milk production, it seems wise to feed as much protein as is called for by the Savage standard when maximum milk production is desired.

In experiments continued over many years, cows have been fed from 30 to 100 percent more protein than is recommended by the Savage standard. The results indicate that cows may consume at least 30 percent more protein than is recommended by the Savage standard without any bad effects on their health or performance.

THE FAT REQUIREMENT

Recent experiments have shown that the milk yield of cows tends to be noticeably reduced when the quantity of total fat—as distinguished from digestible fat—in the ration falls below 70 percent of that secreted in the milk (*769, p. 417; 819, p. 494*). The fat requirement for maximum milk production may therefore be said to be about equal to 70 percent of the fat secreted in the milk. Cows fed according to the procedure previously outlined and giving from 6,000 to 12,000 pounds of milk annually would receive in their food only 70 to 90 percent of the fat secreted in the milk, in spite of the fact that they were fed liberal quantities of a grain mixture containing 30 percent of oil meal in which the fat had not been extracted by solvents. As oil meal of this character contains more fat than corn or the cereal grains and much more fat than hay or than oil meal from which the fat has been extracted by solvents, it is difficult to see how cows on dry barn rations could be supplied with sufficient fat without feeding liberal quantities of the old-process oil meals. The high fat content of these feeds, in addition to their high protein and high phosphorus contents, is probably an additional factor in making them almost indispensable foods for the maintenance of high levels of milk yield in good dairy cows.

No bad effects on the health of cows have been observed as the result of feeding rations too low in fat to support maximum milk yield. The only effect of such feeding that has been so far observed is a reduction in the yield of milk, and it is interesting that this occurs without any accompanying reduction in the percentage of fat. The situation is in marked contrast to the effects of low protein feeding, which may greatly reduce the percentage of fat in the milk as well as the total yield.

THE VITAMIN A REQUIREMENT

Before discussing the vitamin A requirement of cattle, it will be worth while to give a very brief outline of what is known at present regarding the chemistry of this vitamin (see also the article on Vitamin Needs of Man, p. 221). Vitamin A has been identified in animals, particularly in their liver oils, as a definite colorless chemical compound of which the formula is known. This compound itself is not found in plants, but many plants contain yellow pigments called carotenes, the chemical formulas of which are closely related to that of the colorless form of vitamin A found in animals. Animals fed carotene can easily convert it in their bodies into vitamin A. Because of this conversion of the carotene of plants into true vitamin A, it will sometimes be convenient in the following discussion to speak of the carotene content of plants as their vitamin A content.

Plants contain a number of different chemical modifications of carotene. Of these, β-carotene has the highest vitamin A activity. In addition, plants contain other yellow pigments closely related chemically to carotene but without vitamin A activity. Finally, plants that have been converted into hay by drying or have been ensiled contain degeneration products of carotene which have little or no vitamin A activity.

Carotene is usually determined in plant materials by the Willstätter and Stoll procedure or some modification of it. The figures given below were obtained by a modification of this procedure. They can be taken as representing within 10 percent the carotene content and vitamin A activity of fresh growing grass and alfalfa and of carrots, but in the case of hays and silage the carotene content and vitamin A activity is 18 to 40 percent less than is represented by these figures, the largest discrepancies being found in the low-grade hays.

Fresh growing pasture grass and alfalfa contain 300 to 600 parts per million of carotene on a dry-matter basis; yellow garden carrots,[10] about 1,000 p. p. m.; U. S. No. 1 alfalfa hay, 40; U. S. No. 1 clover hay light timothy mixed, 18; U. S. No. 1 timothy hay, 20; U. S. No. 3 alfalfa hay, 4; U. S. No. 3 timothy hay, 5; and corn silage, 39 p. p. m. Yellow corn contains 5 p. p. m. of carotene on a dry-matter basis according to the Willstätter and Stoll procedure, but more than three-fourths of this is cryptoxanthin and other pigments that have only half as much vitamin A activity as β-carotene. Grains and concentrates other than yellow corn have practically no carotene or vitamin A activity, so far as is known at present. From these figures it is evident that most cows are highly dependent on hay and silage of good quality and on pasture for their supply of vitamin A.

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[10] The carotene content of carrots is closely correlated with their yellow color. White field carrots contain only a small fraction of the quantity characteristic of yellow garden carrots.

All of these figures are subject to great variation in individual samples, particularly in the case of silage and the hays. The averages for these feeds are based on 10 to 40 separate analyses for each. They give as good an idea of the situation as can be obtained at present but will no doubt be more or less modified as more determinations are made.

The experiments so far carried out indicate that dairy cows will receive about the minimum carotene required for successful reproduction when the dry matter of their rations contains 10 p. p. m. of carotene. Approximately this quantity is supplied when the rations consist of equal parts of grain and hay, if the hay is U. S. No. 1 clover or U. S. No. 1 timothy.

Animals fed on rations rich in vitamin A can store this vitamin in their bodies and thus remain in good health through a subsequent period when the supply is deficient. Good pasture is rich in vitamin A, and it is a question of practical importance how far a summer on good pasture will protect dairy cows against the effects of living on hay of low quality through the winter.

Experiments carried out to throw light on this subject have shown that good pasture through the summer does protect cows against the effects of moderate vitamin A deficiencies in the winter. If, for instance, cows are fed on grain combined with timothy hay containing about 12 p. p. m. of carotene as the sole roughage for a year, there are likely to be a good many premature calvings after the first 5 months. The same kind of hay fed for 6 months after a summer on good pasture does not cause premature calvings. But if cows are fed on good pasture through the summer and then on U. S. No. 3 timothy hay, which contains only 5 p. p. m. of carotene as the sole roughage, they are likely to begin calving prematurely after 5 months on the poor hay.

The carotene and vitamin A content of milk fat is highly dependent on the quantity of carotene contained in the cow's food. A ration containing 10 to 20 p. p. m. of carotene will supply enough of this pigment to keep cows reproducing normally, but it is far from sufficient to keep the carotene and vitamin A content of the milk fat at its maximum. Even when the best hay is fed, the vitamin A potency of the milk fat still remains far below the figure to which it can be raised by turning cows out on good pasture.

Just how much vitamin A milk fat should contain in order to supply the requirement of human beings is a complicated question that is still a long way from being solved. But it seems likely that milk that is to be fed to infants should contain more vitamin A than is supplied by the rations of mediocre hay frequently fed to dairy cows through the winter.

Vitamin A deficiencies are likely to occur where the quality of the hay crop is poor as a result of unfortunate conditions during curing, or where legume hay is not available, or where the roughage fed is reduced in amount on account of the cheapness of such concentrate byproducts as cottonseed meal. In the case of cattle on range or pasture, very serious vitamin A deficiency may be caused by long-continued drought.

Mature cows suffering from vitamin A deficiency show the condition first by premature calving or by the throwing of weak or dead calves. This abnormality in reproduction is likely to appear in 5 months if the roughage of the ration consists entirely of either U. S. No. 3 alfalfa or U. S. No. 3 timothy hay. After 2 or 3 years on such rations, the cows are likely to fail to conceive though bred many times, and finally to die of some severe infection of either the lungs, the intestinal tract, or the udder.

Calves less than 6 months old are likely to show the effects of vitamin A deficiency by marked retardation in growth, and finally by death from calf pneumonia. Blindness and infections of the eyes also are not infrequent symptoms.

The effects of vitamin A deficiencies in farm foods can be warded off by feeding certain concentrated sources of the vitamin, such as young growing grass or legumes, yellow garden carrots, cod-liver oil, and alfalfa-leaf meal of high quality. Young growing grass is the best and safest source and should be used wherever possible. Under drought conditions, of course, such material is not available, and it will sometimes be worth while to import cod-liver oil or alfalfa-leaf meal. Cod-liver oil must be used with some caution. To many animals, such as sheep, goats, rabbits, and guinea pigs, it is poisonous. Cattle resist its poisonous properties except when it is fed in large doses, but it has, in their case, the peculiar effect of reducing the quantity of fat in the milk. It should be bought under a guarantee as to its vitamin A content and should not be given to adult cows in doses of more than 2 ounces daily, or to calves in doses of more than 1 ounce. Alfalfa-leaf meal readily loses its vitamin A potency. It should be bought under a guarantee in regard to this potency, and should not be kept more than a few months.

Supplementing poor roughage with concentrated sources of vitamin A should be regarded as a temporary expedient to tide over an emergency; it cannot, for the present, be recommended as a permanent practice. One reason for this is that poor roughage is likely to be deficient in dietary essentials other than vitamin A, and the effects of these other deficiencies would appear if the animals were fed long enough on the poor roughage with the vitamin A supplements. Again and again, in nutritional experiments, supplementing deficient rations with vitamin concentrates has warded off nutritional disasters only for a time. It will be worth while, in this connection, to give a brief account of how far experiments on the particular subject under consideration have been carried.

Heifers can be reared successfully without any hay of good quality up to the age of first calving (fig. 2) by the following procedure:

For the first 3 days after birth they are given the colostrum from their dams, which is necessary to provide them with the requisite resistance to early infections. From 3 days to 3 weeks of age they are fed on skim milk supplemented with three-quarters of an ounce of cod-liver oil daily. The skim-milk feeding is continued up to the age of 6 months, but from the age of 3 weeks they are given gradually increasing quantities of grain and U. S. No. 3 timothy hay up to the time of first calving. The feeding of three-quarters of an ounce of cod-liver oil daily is continued through the first year, after which the dose may be increased to 1½ ounces until the time of first calving.

The effects of adding cod-liver oil to the rations of milking cows on poor roughage in quantities fully sufficient to supply their vitamin A requirement have not been studied on account of the fact that cod-liver oil reduces the percentage of fat in the milk. Milking cows have, however, been kept on rations of grain, U. S. No. 3 timothy hay, and three-quarters of an ounce of cod-liver oil daily, which was sufficient to raise considerably the vitamin A content of the ration. They have also been kept on the same basal ration with a supplement of 20 pounds of yellow garden carrots daily while they were milking and 5 pounds daily while they were dry. This was more than sufficient to supply the vitamin A requirement.

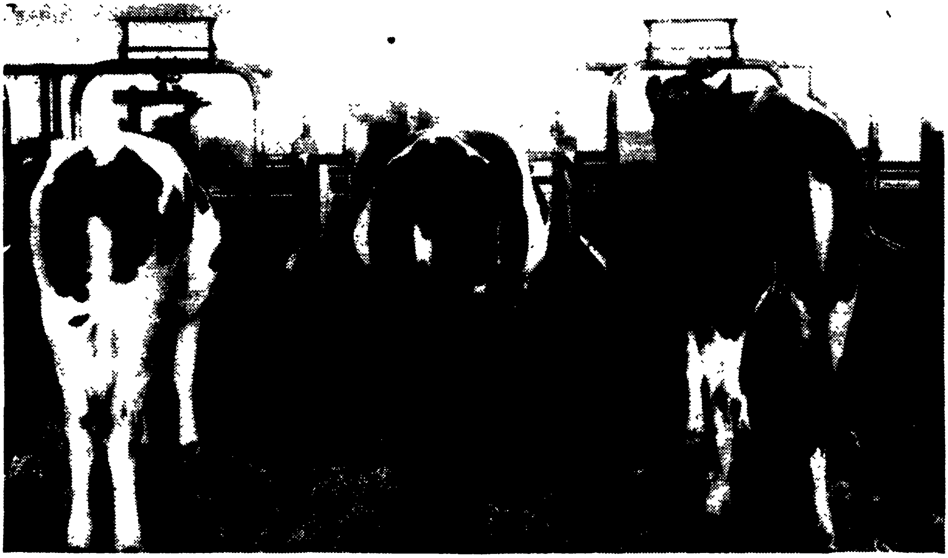

Figure 2.—**On a ration of grain and U. S. No. 3 timothy hay, with a cod-liver oil supplement, the heifer on the left weighs at 1 year 532 pounds, only 148 pounds less than the 2-year-old heifer in the center, which was stunted by a deficiency of vitamin A. The healthy 2-year-old on the right, raised on grain, alfalfa hay, and pasture, weighs 952 pounds.**

During the period of these experiments the herd was more than usually subject to various accidental circumstances which have somewhat clouded the results. It has been clear that the results with both of these supplements have been much better than with the basal rations alone, though they were not so good as when legume hay of good quality formed a considerable part of the ration. With the cod-liver oil supplement there have been slightly less than 80 percent of normal calvings, and with the carrot supplement slightly less than 50 percent. Because of the small number of animals involved, however, and the accidental circumstances referred to, these figures should be regarded as subject to correction. With both rations there have been some normal calvings after the cows had been on them for about 4 years. No large milk yields have so far been obtained on either ration.

THE CALCIUM AND PHOSPHORUS REQUIREMENTS

Calcium

The calcium requirement of mammals is closely connected with the phosphorus requirement, as the two elements are stored together in nearly fixed proportions in the bones, and secreted together in nearly fixed proportions in the milk. If either element is deficient in the ration, both bone building and milk secretion are hindered.

It is an old observation that cattle on range are likely to show softening of the bones and frequent fractures in periods of drought, and it seemed natural to attribute this to a deficiency of calcium in the range material. With the passage of time, however, it has become clear that such changes in the bones are more likely to be due to phosphorus deficiency. The evidence as it stands at present indicates that dairy cows can remain in normal condition with much smaller quantities of calcium in their food than was formerly supposed.

Experiments have shown (*769, p. 381*) that dairy cows may reproduce normally for 3 years on a ration the dry matter of which contained only 0.18 percent of calcium, and then for 2 years more during which the calcium was still further reduced, to 0.12 percent. There was some loss of calcium from the bones under these conditions, and these rations must therefore be regarded as supplying less calcium than was desirable. A consideration of other experimental work indicates that dairy cows giving liberal quantities of milk should receive rations in which the calcium amounts to at least 0.25 percent of the dry matter.

The quantities of calcium contained in several farm feeds are given by Morrison (*819*) and from these figures it can be seen that the minimum calcium requirement would be supplied by feeds quite low in calcium. Timothy hay, for instance, has an average calcium content of 0.27 percent—lower than that of most other roughages. A grain mixture made up of 4 parts corn meal, 3 parts wheat bran, and 3 parts linseed-oil meal would contain 0.14 percent of calcium. Cows receiving a ration of 12 pounds of such a grain mixture and 12 pounds of timothy hay with the average calcium content would receive calcium equal to about 0.20 percent of the dry matter of the whole ration. This is more than was found necessary to keep reproduction normal over a period of 5 years and not very much less than the 0.25 percent recommended as a minimum figure for cows giving liberal quantities of milk. If 3 pounds of alfalfa hay with the average calcium content were added to the above-described ration, the calcium content of the ration would be raised to 0.34 percent, higher than any of the figures suggested by Maynard as the calcium content of the ration required by dairy cows (*769, p. 434*). The evidence at present at hand, therefore, indicates that dairy cows are not likely to suffer from calcium deficiencies except under rather unusual conditions.

There is definite evidence for the view that when the calcium content of the ration is less than 0.25 percent of the dry matter, dairy cows are likely to suffer some loss of bone material; but apparently such loss may occur to some extent without bringing about any abnormality in reproduction.

Becker and his collaborators (*84*) have reported that rations low in calcium have caused fragility of the bones and reduction in the milk yield of dairy cows, and that these symptoms have been corrected by the addition of bonemeal. The calcium content of the basal barn rations was only about 0.18 percent of the dry matter. No figures are given for the calcium content of the pasture consumed by the cows.

Phosphorus

Phosphorus deficiency is a more common cause of trouble with cattle than calcium deficiency, because the soil in certain parts of the world is deficient in phosphorus, and roughage grown on such soil is also deficient in it. Cattle in these regions suffer from phosphorus deficiency when they are fed exclusively on home-grown roughage or when they are fed on such roughage combined with concentrates low in phosphorus, such as corn meal.

Phosphorus-deficient regions have been observed in the United States in certain sections of California, Colorado, Florida, Minnesota, Montana, Nevada, New Mexico, North Dakota, South Dakota, Utah, and Wisconsin. A map showing more precisely the areas of phosphorus deficiency is given in another part of this Yearbook (p. 1029).

Recent work indicates that the rations of dairy cattle should contain phosphorus to the extent of 0.25 to 0.30 percent of the dry matter (*769, p. 434*). The average phosphorus content of many roughages falls below 0.25 percent (*819*), and it is easy to see how dairy cattle fed exclusively on roughage might suffer from phosphorus deficiency if the roughage contained this mineral in unusually low quantity. The feeding of concentrates, however, would greatly decrease the danger of phosphorus deficiency. Even corn meal, which has an unusually low phosphorus content for a concentrate, contains 0.28 percent, and wheat bran and the oil meals contain 0.75 percent or more of this mineral (*819*).

The effects of phosphorus deficiency on dairy cattle have been much studied in the phosphorus-deficient areas of the world. They consist of loss of appetite, often combined with an abnormal craving for unusual foods. The fertility of the cows is much reduced, owing to their failure to become pregnant when bred, and their milk yield is also reduced. In severe cases the mineral matter of the bones is depleted and fractures occur frequently. In less severe cases, the phosphorus content of the blood is reduced, and this may be used as a diagnostic sign of the condition (*769, pp. 431–432*).

Animals on phosphorus-deficient rations are often greatly benefited by the addition of bonemeal or some mineral source of phosphate to the food. It would be difficult, however, to keep good dairy cows near maximum milk production without giving them one or more of the concentrates rich in phosphorus, such as wheat bran or the oil meals.

Organic Factors Concerned in Calcium and Phosphorus Assimilation

It is well established that the growth of bones in young rats and other animals is aided by a group of chemical compounds which has been called vitamin D. These compounds may be supplied in the food or may be produced in the blood and tissues of animals by the action of direct sunlight. As dairy cows that are producing large quantities of milk are likely to be losing calcium and phosphorus from their bodies, much attention has been given to the question whether these losses could be prevented or whether the storage of calcium and phosphorus in the cow's body during the dry period could be promoted either by vitamin D or by any other organic factor in the food.

There is a good deal of evidence to indicate that calcium and phosphorus are better assimilated by dairy cows from pasture, fresh green plant material, and hay of good quality than they are from hay of poor quality, bonemeal, or inorganic calcium phosphates. It has not been found possible up to the present time, however, to promote the storage of calcium and phosphorus in dry cows or to prevent the losses of these elements which often occur during lactation by feeding any form of vitamin D (*769*). There is no evidence at present that adult cows under practical conditions ever fail to get sufficient vitamin D from their rations and from sunlight, or that the feeding of concentrated preparations of vitamin D has any favorable effect on their health or milk yield.

THE IODINE REQUIREMENT

Iodine is usually present in a wide variety of farm feeds in sufficient quantity to provide as much of this element as is required by dairy cows. There are areas, however, in the Great Lakes region and in the northwestern part of the United States, as well as in other parts of the world, where iodine is deficient in the soil and consequently also in the forage and grain grown in those areas, and where the iodine deficiency in the food causes pathological changes in farm animals (*769*). In dairy cows these changes show themselves in the birth of weak and dead calves with tumors in their necks. These are goiters, which consist of an enlargement of the thyroid gland.

Iodine deficiencies can be corrected by adding 0.02 percent of potassium iodide to the salt given (*769*). No benefit is obtained, however, from feeding iodine to animals unless there is a deficiency in the food. As goiter in cattle is a very definite and constant symptom of this deficiency, it may be assumed that the deficiency does not exist unless goiter appears.

GENERAL DISCUSSION OF DIETARY DEFICIENCIES

The requirements of dairy cows for nutritive energy, protein, fat, vitamin A, calcium, phosphorus, and iodine have been discussed. The effects of deficiencies in the first three of these essentials differ in an interesting way from those of the last four. When cattle are fed moderately deficient quantities of nutritive energy, protein, or fat they decrease in body weight or milk yield or both, but their health is not damaged unless the underfeeding is carried very far. Deficiencies in minerals or vitamins, on the other hand, produce the pathological effects which have been described. It is important for dairy farmers to be familiar with the effects of these various deficiencies, so that they may be able to attribute pathological conditions appearing in the herd to their true sources and take the proper steps for their correction.

The deficiencies of vitamin A, calcium, phosphorus, and iodine are the only important vitamin and mineral deficiencies that have been observed to produce pathological changes in dairy cows under practical conditions. The possibility that deficiencies of vitamins B_1, C, and E might cause pathological changes has been studied, and the results so far have shown that it is difficult if not impossible to produce such changes in ruminants by feeding them rations deficient in these vitamins even under experimental conditions. Maynard (*769*) gives an account of experiments showing that vitamins B_1 and C are not required in the food of cattle and also reports others indicating that vitamin E is not required by goats and swine. Ruminants differ from other mammals in being provided with a paunch in which the plant material eaten is kept for several hours and subjected to bacterial activity. Experiments have indicated that bacterial action going on in the paunch of cattle is capable of producing some of the factors that make up vitamin B (*769*), and it seems likely that such bacterial action may provide cattle with other organic dietary essentials required by nonruminating animals directly in their food. Other vitamins and minerals needed by cattle are so widely distributed in natural foods that the effects of their deficiency have not yet been detected under practical conditions.

The procedure for the feeding and treatment of dairy cattle given in this article provides more protein than is called for by any of the studies of protein requirement, but very little more fat than is required according to the recent results reported by Maynard (*769*). The protein and fat of the rations under consideration is largely supplied by the oil meals they contain. Oil meals that have not been extracted by fat solvents contain more fat than the cereal grains and much more than the hays. It is difficult to see how cows on barn rations could be supplied with sufficient fat without including considerable proportions of oil meals in the concentrate mixture. Further, some legume hay is required in the dairy ration on account of its superior mineral and vitamin content, and legume hay, like the oil meals, is high in protein. It is difficult, therefore, to make up a dairy ration from the farm foods now on the market in such a manner that it will contain sufficient fat, minerals, and vitamins without more protein than is required. The excellent results widely obtained with dairy rations containing liberal quantities of oil meal and legume hay are sufficient evidence that a moderate excess of protein does no harm provided the ration contains all the other nutritive essentials in sufficient quantities. There is room for further experiment on the advisability of supplying fat in the dairy ration in some other form than as a constituent of the oil meals.

The rations recommended contained about 20 p. p. m. of carotene instead of the 10 that have been found to be the minimum required for normal reproduction. They contained about 0.56 percent of calcium and 0.44 of phosphorus, as against the 0.25 to 0.30 percent of each of these elements that has been determined as the requirement for dairy cows. Where these animals are being fed for maximum milk production, it seems wise to feed more of these important dietary essentials than the quantities experimentally determined to be near the minimum requirement. As the cows fed and treated as described remained in good health and gave liberal quantities of milk, it may be concluded that the surplus dietary constitutents did no harm.

SUBSTITUTION OF OTHER FARM FEEDS FOR THOSE SUGGESTED

There is every reason to think that dairy cows would do well on rations in which other similar farm foods were substituted for those that have been mentioned in this article as having been subjected to actual experiment. Corn meal, for instance, can be replaced satisfactorily by other grains of similar composition, such as oats and barley; cottonseed meal, by other oil meals; alfalfa hay by other legume hays; and so on indefinitely.

A number of long-continued experiments have actually been carried out in which grain has been fed with single roughages other than the combination of alfalfa and timothy which was found to be so satisfactory. The cows were, of course, kept entirely off pasture. The roughages studied were U. S. No. 1 clover hay light timothy mixed, U. S. No. 1 timothy hay, U. S. No. 3 timothy hay, U. S. No. 3 alfalfa hay, and corn silage. The results with the U. S. No. 3 alfalfa and U. S. No. 3 timothy hay were uniformly unsatisfactory, no living healthy calves being obtained after these rations had been fed for as much as 6 months. The results with the other rations were variable and by no means as satisfactory as with the combination of U. S. No. 1 alfalfa and U. S. No. 1 timothy hay. The proportion of weak and dead calves born on these rations ranged around 50 percent. Investigation showed that the chief shortage in the rations under consideration was of carotene. The rations of U. S. No. 3 alfalfa and timothy hay, on which all of the calves were born dead or weak after a few months, contained only very small quantities of carotene, while the other rations contained intermediate and variable amounts. All of the rations were improved by adding concentrated sources of vitamin A, as has already been said in the discussion of carotene requirements; and the rations containing intermediate and variable amounts of carotene produced no bad results when they were fed only in the winter and the cows were out on good pasture through the summer. Good pasture, containing some legumes and some grass, may be regarded as insurance against all sorts of vitamin and mineral deficiencies, and farmers who can provide their cows with such pasture for 5 or 6 months in the summer need have much less anxiety about incurring pathological effects by feeding hay that is not of the very best quality through the winter. But it should not be forgotten that the vitamin A potency of the milk and butter will be much reduced in a month or so on mediocre hay even after the cows have been on the very best of pasture previously.

SOME UNFORTUNATE RESULTS OF THE DISCOVERY OF DIETARY DEFICIENCIES

Whenever it has been discovered that some pathological condition is due to a dietary deficiency, some organizations and individuals have tried to make as much money out of the new discovery as possible. The course taken by these groups has always been about the same, and may be illustrated by events that have taken place in connection with the discovery of calcium and phosphorus deficiencies. In the first place it is represented that the deficiency is much more widespread than it really is. In the case of calcium and phosphorus, for instance, the situation really is that these deficiencies occur only under certain not very common conditions of feeding and in certain restricted areas of the world. The pathological results of the deficiencies are also specific and not difficult to recognize. By certain groups who wish to sell mineral mixtures, however, it is represented that farm animals everywhere suffer from calcium and phosphorus deficiencies—indeed, that most of the ills from which they suffer are due to such deficiencies. To cure these numerous ills it is represented that the mineral mixture put out by such and such a firm is especially potent. As a matter of fact, the tests that have been made with such preparations are usually very scanty and inadequate. In particular, it has turned out that calcium and phosphorus mixtures have frequently been made from rock phosphate, which is a cheap source of calcium phosphate. Rock phosphate usually contains fluorine, an element that is poisonous in the quantities in which it is contained in the rock phosphate. It takes some weeks or months, however, for its poisonous effects to make themselves manifest, and certain rock-phosphate preparations put on the market as supplements for cattle feeds have had disastrous effects on the health of cattle when fed for any length of time.

This is not the only known example of poisonous preparations being put on the market and widely advertised as beneficial supplements to feeds. Soon after the importance of vitamin A in the rations of dairy cattle was discovered, it was widely advertised that cod-liver oil or some preparation made therefrom should be added generally to the rations of farm animals. But it has been known for some time that cod-liver oil reduces the fat in the milk of dairy cows, and it has more recently become clear that, although cattle tolerate this drug fairly well, other animals such as sheep, goats, rabbits, and guinea pigs are readily poisoned by quite small doses of it.

It should be emphasized, therefore, that when animals are fed on the proper natural rations, mineral and vitamin supplements are unnecessary, and that it is not safe to assume that such preparations are harmless. The price the farmer gets for his products ought to be adjusted to make the feeding of good natural rations economically possible, for it is far too early to say yet whether any of the manufactured mineral and vitamin products can be used successfully as supplements to inferior natural foods over long periods. Experience has shown that they can be used to tide over certain emergencies, but even when they are used for this purpose they should be subjected to the supervision of the experiment stations.

ESSENTIALS OF DAIRY CATTLE FEEDING

Before cattle were domesticated, they subsisted on roughage and were able to get from this kind of food sufficient nutritive energy and nutritive essentials of all kinds to keep themselves in a state of fertility and to enable them to supply enough milk for the nourishment of their calves. As the milking function became exaggerated under domestication, it was found advantageous to feed more concentrated food in the form of grain. Still more recently, manufactured high-protein concentrates have been introduced into the dairy ration, and milk yields have risen to the astonishing point where some cows can furnish enough milk in a year to nourish half a dozen calves or more. The experiments that have been considered in this article show that the modern high-producing cow can be largely nourished on grain and high-protein concentrates and kept in good health and at a high level of milk production and fertility through the normal period of her life, provided she receives, in addition to the concentrates, liberal quantities of roughage of the proper kind and of good quality. One generation of cows can be maintained on concentrates and dried roughage of good quality without any fresh green feed and without the free choice of foods which is provided when cows are turned out on pasture. But when a herd of cows is maintained on barn feeding with dried feeds only, the second generation is likely to show reduced fertility. The evidence at present at hand indicates that this can be avoided if the herd is turned out for a few months on good pasture every summer. Pasture not only tends to keep up the fertility of the herd, but also provides the cows with a surplus of various known and unknown nutritive essentials that can be stored in their bodies and thus insure them against such deficiencies as might occur from the feeding of roughage not of the highest quality through the winter.

It is undoubtedly the best and safest procedure, under present conditions of knowledge, to provide the necessary minerals and vitamins as a part of such well-tried concentrates and roughages as those which have been suggested. If farmers desire to economize by feeding unbalanced concentrate mixtures and roughages of inferior quality, making up for deficiencies in such rations by feeding vitamin and mineral preparations, they should realize that they are entering the experimental field. They are departing from rations shown to be satisfactory by long years of practical experience, and are initiating practices that may turn out to be successful, but are much more likely to result after several years in some obscure pathological condition of dietary origin, which it may take years of careful experimentation to trace to its source.

FIGURING THE RATIONS OF DAIRY COWS

by T. E. Woodward [1]

THIS article contains material that supplements the preceding article on The Feeding of Dairy Cows for Intensive Milk Production in Practice. Primarily, the author is concerned with figuring the varying quantities of grain mixture that should be used to supplement roughage, including pasture. He considers this problem in relation to the breed of the cow, the season of the year, and the region in which the producer lives.

GRAIN MIXTURES

THE QUANTITY of protein needed in the grain ration of dairy cattle depends on the quantity supplied by the forage crops fed. As it is impracticable to attempt to feed each cow only as much protein as it actually requires, the aim should be to use a grain mixture of such composition that the cows with the highest requirement will be getting enough protein even though this will mean that some of the cows with lower requirements are getting an excess. There are hundreds of combinations of grains that can be used, and a great many are being used successfully. Grain mixtures made up of a few standard feeds and adapted for feeding with roughages of different kinds are shown in table 1. Other feeds may be substituted wholly or in part for the feeds specified in the table. It is assumed that the forages to be fed will be at least of average quality, that silage when used will be fed at the rate of about 3 pounds per 100 pounds of body weight of the animal, and that at least 1¼ pounds of hay per 100 pounds of body weight will be eaten in addition to the silage.

Part or all of the corn in the mixtures in table 1 may be replaced by barley, wheat, kafir, or hominy feed. Part of the oats may be replaced by barley, wheat, kafir, hominy feed, or corn. Two parts of gluten feed or dried brewers' grain may replace 1 part of oats and 1 part of cottonseed meal. Linseed meal, peanut meal, ground soybeans, soybean meal, or fish meal may be substituted for part or all of the cottonseed meal. High-grade tankage may be substituted for cottonseed meal at the rate of 2 pounds of tankage for each 3 pounds of cottonseed meal. Until further investigations are conducted it is suggested that the quantity of fish meal should not exceed 10 percent of the grain mixture and that the quantity of tankage should not exceed 20 percent.

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TABLE 1.—*Grain mixtures having different protein contents to be fed with different roughages*

Roughage	Approximate total protein content desired in grain mixture	Grain mixture			
		Ground corn	Ground oats	Wheat bran	Cottonseed meal
	Percent	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Legume hay [1] alone	12	400	200	200	---- -----
Legume hay and silage, or mixed hay [2] alone	16	300	200	200	100
Mixed hay [2] and silage	20	200	200	200	200
Grass hay and silage or either alone	24	100	200	200	300

[1] If clover, add 100 pounds of cottonseed meal to the grain mixture.
[2] One-half grass and one-half legume.

On the basis of the energy value of the feeds, good hay is worth about 60 percent as much as the usual grain mixture, and silage is worth about one-third as much as good hay. If it should happen, therefore, that hay and silage cost more per unit of nutritive value than grains, it will pay to reduce the roughage allowance in the ration and to increase the grain; but in no case should the roughage be reduced to a point at which mineral or vitamin deficiencies may be encountered. Usually it will be inadvisable to reduce the roughage below an amount that will supply enough total digestible nutrients for maintenance. This will be about 1¼ pounds of hay or hay equivalent (1 pound of hay is equal to 3 pounds of silage) per 100 pounds of body weight of the animal. Every reduction of 1 pound in the hay or hay equivalent fed will mean an addition of 0.6 pound of grain in order to provide a similar quantity of nutrients.

The quantity of feed required over and above that needed for maintenance is directly proportional both to the quantity of milk produced and to the energy value of the milk. The nutrients required vary with the percentage of fat in the milk, but not proportionally so.

One pound of a good grain mixture will have about 0.75 pound of digestible nutrients. After maintenance requirements are met, the amounts of grain needed for each pound of average milk produced by the different dairy breeds are shown in table 2.

TABLE 2.—*Amounts of grain needed for each pound of average milk produced by different breeds and digestible nutrients represented*

Breed	Grain mixture	Digestible nutrients
	Pound	*Pound*
Holstein-Fresian	0.41	0.307
Ayrshire and Brown Swiss	46	.340
Guernsey	.52	.391
Jersey	.56	.419

SUMMER FEEDING

Good pasture provides the best feed there is for dairy cows, and besides is usually cheaper than harvested crops. Good pasture herbage contains all the factors required for perfect nutrition. If cows are permitted to graze such herbage, any nutritive elements that may have become depleted through the feeding of poor-quality roughage during the winter will be automatically restored in their bodies. Pasturage has always been and still is a lifesaver for dairy cattle.

Good pasturage is young, tender, abundant, and grown upon soils that are not seriously lacking in any of the essential mineral elements. Such pasturage is inadequate for dairy cows in only one respect. Cows will graze about 150 pounds a day, which means a dry-matter intake of 30 or more pounds. If no allowance is made for the energy used in grazing, this is enough above maintenance to support a production of 30 to 45 pounds of milk, depending on the richness of the milk, or nearly 1½ pounds of butterfat a day. However, there is no justification for disregarding the energy used in grazing. There is some evidence that cows over an entire pasture season actually use for productive purposes—maintenance and milk—only about 75 percent of the nutrients produced by the pasture. How much of the 25-percent discrepancy is due to trampling and soiling and how much is due to the energy used in grazing has not been determined. Perhaps over most of the country good pasturage should not be depended on to provide the nutrients for the production of more than 1 or 1¼ pounds of butterfat a day. Pasturage, therefore, when used as the sole ration, is not a sufficiently concentrated feed to support a heavy production of milk.

Only in certain favored sections of the United States do pastures remain good throughout the whole season. As a rule, they are at their best for not more than a month or so, after which their value declines rapidly. Milk-production surveys show that the milk yields increase markedly at the time the pasturage is at its best, but they also show that the declines in production thereafter are quite rapid. This indicates that good pasturage is unexcelled for the production of milk, but it also indicates that dairymen depend too much upon their pastures. Either supplementary pasturage must be provided for use after the flush season, or more grain, hay, or silage must be fed. Since it is impossible to tell by looking at a pasture how much grass cows will graze from it, an estimation of the supplementary feed required cannot be made in that way. It is therefore suggested that cows be allowed all the good hay they will eat throughout the pasture season. When the grass is good they will eat very little hay, but as it becomes poorer they will eat more and in this way automatically tend to make up for what the pasture lacks. Silage can be fed to replace part or all of the hay if the quantity of feed needed is sufficient to permit the silage to be fed fast enough to prevent its spoiling.

In localities where it pays to feed grain in winter, it usually pays also in summer. With the exception of the last 2 years, when Government purchases have kept the price of butter almost constant throughout the summer, milk prices have ranged considerably lower in summer than in winter. Even then, it has as a rule paid to feed grain in addition to pasture to cows producing at a fairly heavy rate. Even if the margin between the price of milk and grain is a narrow one, there is also the condition of the cows to consider. Without grain good cows lose flesh to such a degree that production is depressed later in summer when milk prices improve and below the natural level for the cow later in lactation—a level that otherwise could be sustained on forage. In addition to pasture and hay or silage, grain may be fed for all production over 1 to 1¼ pounds of butterfat a day while the grass is at its best. The grain may be increased if the pasturage for any reason becomes poorer. As long as the pasturage remains reasonably good, it should not be necessary to provide grain for any production below two-thirds of a pound of butterfat a day.

An example will show how this method is applied. A Jersey cow on a fairly good pasture is producing 30 pounds of milk testing 5 percent. Thirteen pounds of this milk (0.65 pound of butterfat) will be supported by the pasturage and hay, leaving 17 pounds that must be supported by grain. Seventeen times 0.56, the quantity of grain required for 1 pound of Jersey milk, equals 9.5 pounds of grain—the quantity to be fed daily in additon to pasturage and hay.

It should be emphasized that ordinarily the greatest declines in milk production take place as soon as the quality of the pasturage begins to decline—in July in the Northern States and in June in the States a little farther south. It should also be emphasized that the effects of loss of milk and flesh at this season are carried over into the late summer and fall. It seems that midsummer is the time when the greatest improvement in the feeding of cows can be made.

WINTER FEEDING

The aim in winter feeding should be to get the milking cows to eat as much of the forages as possible and to feed only as much concentrates as are required to bring the total nutrients up to the required level. Investigations have shown that cows in the West fed exclusively on good alfalfa hay produce at least 1 pound of butterfat a day—provided, of course, that they are inherently capable of producing this quantity. Alfalfa is usually cheap in these regions of the West, and grain may be relatively expensive. These facts, combined with a low price for the product, may make the feeding of roughage as the sole ration the most economical practice. Investigations have shown also that the addition of grain to the ration improves production. If the price of the grain is low enough or the value of the product is high enough, it may be economical to feed some grain even in those regions where good alfalfa hay is cheap.

Generally speaking, the quality of hay produced farther east, say in the Central States, is not so good because of the less favorable hay-curing weather. For this reason, and also because much of the hay is made from grasses or mixtures of grasses and legumes, rations of hay alone or of hay and silage will not be eaten in as large quantities as the good alfalfa hay produced farther west and cannot be depended on to support a production of as much as 1 pound of butterfat a day. Furthermore, the price of grain is likely to be lower in relation to the price of roughage. Fraser (*392*)[2] estimates that cows should have grain for all production over and above two-thirds of a pound of butterfat a day. This quantity of butterfat would be contained in about 20 pounds of milk from Holsteins, 16 pounds from Ayrshires and Brown Swiss, 14 pounds from Guernseys, and 12 pounds from Jerseys.

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[2] Italic numbers in parentheses refer to Literature Cited, p. 1075.

In the East the hay may be even poorer and the value of milk products higher on the average. A more satisfactory rule in this region is to base the grain feeding on the assumption that roughage alone will support a production of only one-half pound of butterfat a day and that for all production exceeding that amount grain should be fed. This means feeding grain for all production above the following quantities (pounds) of milk: Holsteins, 15; Ayrshires and Brown Swiss, 12; Guernseys, 10; and Jerseys, 9.

As an example of how this method would be applied in the East, let us assume that a Holstein cow is being fed all she will eat of average hay or of hay and silage and is producing 40 pounds of milk a day. Fifteen pounds of the milk will be supported by the forage, leaving 25 pounds to be supported by the grain. Twenty-five times 0.41, the quantity of grain required for 1 pound of Holstein milk, equals 10 pounds of grain—the amount to be fed daily in addition to the hay or hay and silage.

This method of feeding cows in the different regions contemplates providing them with all the average-to-good hay or hay and silage produced in the region that they will eat without undue waste. It is realized that certain modifications of this rule should be made if the price relationships between the feeds themselves and between the feeds and the product change materially. It is also realized that the protein content of the roughage may be so low as to require some high-protein grain even at the lower levels of milk production. The figures are offered only as a general guide. In practice, analyses of feeds usually are not used, and the exact quantities fed are not known. The distribution of the feed to the individual cows can never be done satisfactorily and economically solely on the basis of milk yields and feeding standards. The feeder should observe the condition of the cows as regards flesh. Thin cows should have more and fat cows less than the rule provides. The more extensive use of the artificial drier for hay and, what appears to be more important, the making of hay crops into good silage, offer possibilities of improving the roughage of the East to a point where it will compare favorably with that of the West. If that should happen, the quantity of grain fed could be reduced without reducing the quantity of milk produced.

The methods of feeding described are admittedly somewhat crude, yet they probably represent a considerable advance over present common practices. As dairying becomes more intensive and cultivated crops and fertilized pastures, as well as more valuable hay crops, have to be husbanded carefully to make dairy farming pay, the farmer will no doubt adopt more scientific methods of feeding than the one just described, and an effort will be made to have each cow fed more nearly according to her individual nutritive requirements. Until the practice of frequent weighing of the roughage is combined with the weighing and testing of the milk, the quantity of grain needed to complete the ration must continue to be somewhat a matter of guesswork.

PRACTICAL FEEDING AND NUTRITIONAL REQUIREMENTS OF YOUNG DAIRY STOCK

by Joseph B. Shepherd and H. T. Converse[1]

SOME 5,000,000 to 5,500,000 heifer calves are being saved in the United States each year to keep our dairy herds going. The total number of heifers under 2 years of age being raised for this purpose is about 10,000,000. The heifers of today are the milkers of tomorrow, and good management begins with this young stock. Here are detailed directions for the feeding of young dairy animals from birth through first calving, followed by a discussion of the theory of nutritional requirements for their growth and health.

TWENTY-FIVE MILLION cows 2 years old or older are kept for milk production in the United States.[2] The average dairy cow remains in the milking herd only about 5 years. To replace these cows, between 5,000,000 and 5,500,000 dairy heifers under 1 year of age and approximately 5,000,000 dairy heifers between 1 and 2 years of age are being raised each year.[2]

The 1920 census reported 772,320 dairy bulls of serviceable age (1 year old or older). No separate tabulations have been made for dairy bulls since that time. However, the 1930 census figures show a gradual decline in the total number of bulls between 1920 and 1930. At the same time, there has been a considerable increase in the number of milk cows and heifers of breeding age (1 year old and older).[2] It therefore seems probable that the present number of dairy bulls of serviceable age may be somewhere between 700,000 and 800,000. Except for a few registered bulls whose daughters have proved to be high producers, most dairy sires do not remain in service more than 2 or 3 years. On this basis, it is necessary to raise between 250,000 and 300,000 dairy bulls to a serviceable age each year.

In raising dairy calves for herd replacements the aim should be to raise only calves that will develop into healthy, high-producing stock that will be profitable to the farmer or dairyman. To this end, calves raised should be out of high-producing cows. They should be normal, healthy, and vigorous at birth. They should be sired by a bull of good conformation and breed type whose ability to sire daughters of good type and production has been proved, or by a son of such a proved sire. They should be raised under clean sanitary conditions that will help protect them from disease. They should be fed rations that contain the right kind of high-quality nutrients in quantities sufficient for normal growth and development, but for economical production these nutrients should be provided at the lowest possible cost.

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[2] Based on estimates of the Bureau of Agricultural Economics as given in table 466, p. 337, U. S. Department of Agriculture, Agricultural Statistics, 1938.

In this article the practical feeding of young dairy stock will be considered first. A later section, devoted to the more theoretical aspects of feeding, will discuss nutritional requirements for growth and health and the experimental work that has led to present understanding of these requirements.

PRACTICAL FEEDING

In actual feeding practice, it is more convenient to use age, rather than weight, and quantities of feed, rather than quantities of total digestible nutrients, as guides in feeding. At any given age, heifers fed the quantities of feeds that will provide the nutrients needed for maintenance and normal gains on a normal age-weight basis are less apt to be underfed than heifers fed on a weight basis without regard to age. A feeding guide based on age and quantities of feed in terms of whole milk, fresh skim milk, grain, and good hay or its equivalent, is presented in table 1.[3] Because of breed differences in size for age, separate feed requirements are given for growing heifers of each dairy breed.

These kinds and quantities of feeds provide a normal ration containing moderate quantities of milk and grain and liberal quantities of roughage. The quantities of roughage at different ages are such as will be readily eaten in a ration of this kind if it consists of average good hay that has been cut fairly early and cured with the retention of most of the leaves and some green color. If the hay available is not so good as this, less hay will be eaten and more grain will be required. If the hay available is of the best quality and very palatable, more of it will be consumed, and the quantity of grain fed after the heifers are 9 or 10 months old can be reduced accordingly. Feed substitutions can be made on the basis indicated at the bottom of table 1.

RAISING THE DAIRY CALF TO 6 MONTHS

In the successful raising of young dairy stock the proper care of the calf at birth and during the first few weeks of its life is most important. Once past this critical period without any serious infections or digestive disturbances, the calf will be comparatively easy to raise and will grow well when fed by any one of a number of different methods.

Care and Management of the Young Calf

The calf should be born in a clean, properly disinfected, well-bedded box stall or, during warm weather, on a small well-grassed plot or pasture. The box stall should be kept clean and well bedded while the calf remains with the cow.

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[3] Table 1 gives the quantities of feed that will provide the nutrients called for by the Gullickson-Eckles data (table 9, p. 627) on a normal age-weight basis calculated from the Ragsdale and Fohrman-Swett growth data (table 7, p. 625).

To guard against navel infection, apply tincture of iodine to the calf's navel at birth or soon thereafter, and dust with boric acid powder. If a long cord is attached to the navel, clip it off about 2 inches from the body before applying iodine. Do not tie the cord, but allow it to drain freely to encourage shrinking and healing.

TABLE 1.—*Feed requirements for normal growth of heifers from birth to 2 years in terms of milk, grain, and hay* [1]

Period of life	Ayrshire			Guernsey			Holstein-Friesian and Brown Swiss			Jersey		
	Milk and skim milk	Grain	Good hay equivalent	Milk and skim milk	Grain	Good hay equivalent	Milk and skim milk	Grain	Good hay equivalent	Milk and skim milk	Grain	Good hay equivalent
Daily feed requirement:	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*
First week	7			6			8			5		
Second week	8			7			9			6		
Third week	9	0.1	0.1	8	0.1	0.1	10	0.2	0.1	7	0.1	0.1
Fourth week	10	.2	.2	9	.2	.2	11	.5	.3	8	.2	.2
Fifth week	11	.5	.4	10	.5	.3	12	.8	.5	9	.4	.3
Sixth week	12	.8	.6	11	.8	.4	13	1.0	.7	10	.5	.4
Seventh and eighth weeks	13	1.0	.8	13	1.0	.6	14	1.5	1.0	12	.8	.6
Third month	13	1.5	1.5	13	1.5	1.2	14	2.0	2.0	12	1.2	1.2
Fourth month	13	2.0	3.0	13	2.0	2.5	14	2.5	3.5	12	1.8	2.5
Fifth month	13	2.5	4.0	13	2.5	3.5	14	3.0	4.5	12	2.5	3.5
Sixth month	13	3.0	5.0	13	3.0	4.5	14	3.0	5.5	12	3.0	4.5
Seventh month		3.0	7.2		3.0	6.9		3.0	9.6		3.0	6.8
Eighth month		3.0	7.8		3.0	7.6		3.0	10.5		3.0	7.4
Ninth month		3.0	8.6		3.0	8.4		3.0	11.3		3.0	8.0
Tenth month		3.0	9.4		3.0	9.1		3.0	11.9		3.0	8.6
Eleventh month		3.0	9.9		3.0	9.7		3.0	12.5		3.0	9.0
Twelfth month		3.0	10.5		3.0	10.1		3.0	13.1		3.0	9.4
Thirteenth month		3.0	11.0		3.0	10.5		3.0	13.4		3.0	9.8
Fourteenth month		3.0	11.5		3.0	10.9		3.0	13.8		3.0	10.0
Fifteenth month		3.0	11.9		3.0	11.1		3.0	14.1		3.0	10.3
Sixteenth month		3.0	12.2		3.0	11.3		3.0	14.4		3.0	10.5
Seventeenth month		3.0	12.4		3.0	11.6		3.0	14.7		3.0	10.7
Eighteenth month		3.0	12.8		3.0	11.9		3.0	15.1		3.0	11.0
Nineteenth month		3.0	13.1		3.0	12.2		3.0	15.4		3.0	11.4
Twentieth month		3.0	13.6		3.0	12.5		3.0	15.6		3.0	11.7
Twenty-first month		3.0	13.9		3.0	12.8		3.0	16.1		3.0	12.1
Twenty-second month		3.0	14.5		3.0	13.4		3.0	16.5		3.0	12.7
Twenty-third month		3.0	15.3		3.0	14.2		3.0	17.1		3.0	13.3
Twenty-fourth month		3.0	15.8		3.0	14.7		3.0	17.6		3.0	13.9
Total feed:												
Birth to 6 months	2,252	305	434	2,190	305	376	2,415	367	504	2,007	284	376
6 to 12 months		547	1,621		547	1,572		547	2,081		547	1,493
12 to 18 months		547	2,197		547	2,052		547	2,608		547	1,935
18 to 24 months		547	2,616		547	2,422		547	2,983		547	2,279
Birth to 24 months	2,252	1,946	6,868	2,190	1,946	6,422	2,415	2,008	8,176	2,007	1,925	6,083
Total digestible nutrients in feed:												
Birth to 24 months	209	1,459	3,434	202	1,459	3,211	225	1,505	4,088	184	1,443	3,042

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[1] Calculated from Ragsdale and Fohrman-Swett growth data (table 7, p. 625) and nutrient requirements for growth based on Gullickson-Eckles data (table 9, p. 627). Ayrshire nutrient requirements per pound of gain are based on Holstein-Friesian data and Guernsey requirements are based on Jersey data.

Feed calculations are based on whole milk to 3 weeks with a gradual change to fresh skim milk during the fourth week and average to good hay cut fairly early with the retention of most of its leaves and some green color. Average total digestible nutrient values used for feeds were: Whole milk 16.2 percent, fresh skim milk 8.6, grain 75.0, and hay 50.0 percent. Feed substitutions can be made on the following basis: 3 pounds of silage (made with little or no wilting), 5½ of carrots or rutabagas, 6 of turnips, 7 of mangels, 2 of sweetpotatoes, 2 of fodder (including uneaten portion), or 0.7 pound of grain are equal to 1 pound of hay. 1½ pounds of hay, 8 of carrots or rutabagas, 9 of turnips, 10 of mangels, 3 of sweetpotatoes, or 9 pounds of fresh skim milk are equal to 1 pound of grain.

A normal calf is able to stand shortly after birth, and within a half hour it may be nursing. If the cow's udder is soiled, there is danger of the calf's being infected from this source. Wash the udder with warm water and soap and rub it dry at once with a clean cloth.

Sometimes the calf is so weak that it must be held up to the cow's udder and helped in starting to nurse. If it does not suck at first, milk a small stream into its mouth. If the weak calf cannot be induced to suck by this method, try feeding it warm milk from its mother in a bottle, either with or without a nipple.

If the cow and calf are progressing normally the calf should be taken from the cow within 12 to 24 hours after birth and placed in a small individual pen by itself where it will not be jostled or the navel injured before it has healed. This pen should have tight sides at least 3½ feet high. It should be light and well ventilated but free from drafts and not too cold. It should be thoroughly cleaned and disinfected before the calf is placed in it, and kept well bedded with dry material. The pen should be equipped with a small box for grain and a small slatted rack for hay, as the calf should learn to eat these feeds before it is placed with the other calves.

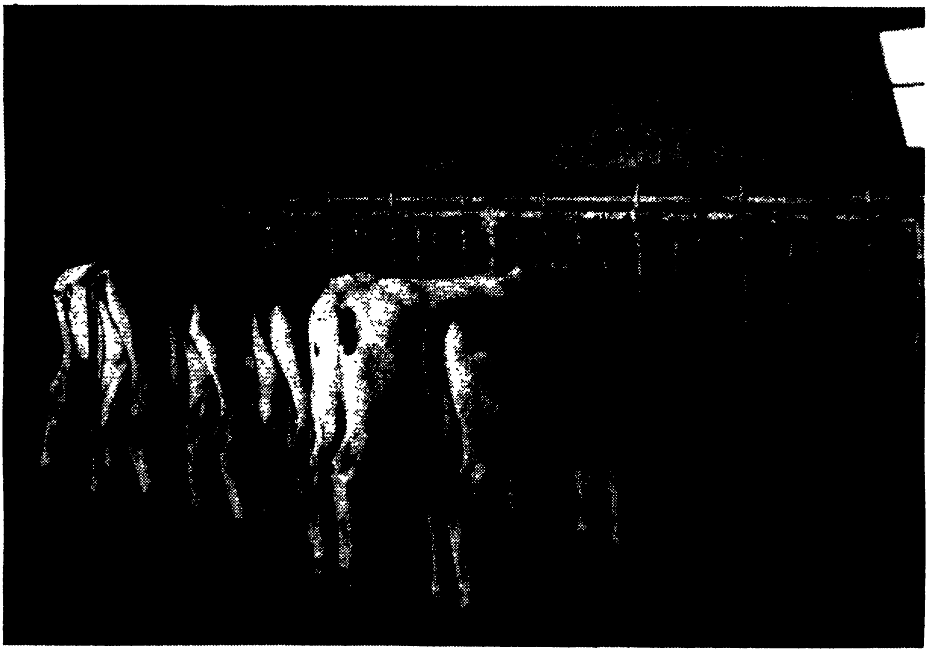

Figure 1.—**Calves fastened in stanchions for individual feeding. These may be made of either wood or steel.**

By the time the calf is 3 or 4 weeks old, its navel has healed and it has gained in strength and vigor. It can then be placed in a larger pen with other calves of the same age. This pen should be equipped with stanchions so that each calf can be fed individually without interference from other calves (fig. 1) and a separate manger or slatted rack should be provided for hay so that the calves can eat hay at any time when not confined to their stanchions. At this age the calves should also have free access to water, and there should be a well-drained lot or small pasture where they can be turned out for exercise and direct sunlight when it is not too cold or windy.

Scrupulous cleanliness should be observed in the feeding of the calves. All milk and other feeds should be fresh and clean. All discarded feed should be removed from the feed boxes each day. After each feeding the pails, cans, and other utensils used in the feeding of milk or gruel should be thoroughly washed and scalded or steamed. If steaming equipment is not available, the utensils should be placed on a drying rack in direct sunlight after they have been washed and scalded.

Feeding dirty milk or milk alternately sweet and sour or warm and cold may bring on indigestion and scours (diarrhea). If the feeding is carefully supervised, milk that is uniformly cold or sour can be successfully fed after the calf is 2 to 3 months of age. Some calves, however, have a tendency to scour on such milk, and it is best to make a practice of feeding only fresh, sweet skim milk. In feeding skim milk it is best to remove most of the foam, as it may sometimes cause the calves to be slightly bloated immediately after feeding.

Milk from cows infected with a communicable disease such as tuberculosis or Bang's disease (infectious abortion), and skim milk, buttermilk, or whey from a creamery or cheese factory should always be pasteurized before being fed. This can be accomplished on the farm by heating to 150° F. and holding at this temperature for 30 minutes, or by heating to 180° and cooling immediately.

Further information on sanitation, the care and management of dairy calves, and the treatment of common diseases and ailments will be found in Farmers' Bulletin 1723, The Feeding, Care, and Management of Young Dairy Stock (*1037*).[4]

Different Methods of Feeding

Whole milk is the best food for the newborn calf. Where skim milk is available, it can be substituted for whole milk when the calf is 2 to 4 weeks old. In the case of normal vigorous calves, skim milk with a vitamin A supplement can be abruptly substituted for whole milk at the end of the 3-day colostrum feeding period. Where skim milk is not available, whole milk may be fed in limited quantities, either by hand or from a nurse cow, for 60, 90, or 120 days. If whole milk is too valuable for feeding in this manner, the calf may be raised on other milk products such as fresh buttermilk, fresh whey, dried skim milk, dried buttermilk, or condensed buttermilk. The dried products may be fed either in liquid form with water added, or dry, mixed in a special grain mixture or calf meal. The calf may also be fed a grain mixture with or without some animal product other than milk. Usually calves raised on grain or a calf meal with limited quantities of milk will not gain as rapidly or be as thrifty during this period as calves fed milk in liberal quantities to 6 months of age.

Beginning at about 2 weeks of age, the calf requires hay of good quality and a suitable grain mixture to supplement these feeds. Later on, it can make good use of silage and pasture.

The choice of a milk product to feed will depend upon availability, quality, and cost per unit of digestible nutrients. The chemical composition and digestible-nutrient content of normal whole milk, colostrum milk, fresh skim milk, fresh buttermilk, fresh whey, dried skim milk, dried buttermilk, and condensed buttermilk are shown in table 2. The relative value of these feeds (except colostrum), based on the total digestible nutrients, in comparison with fresh skim milk priced at 20 to 60 cents per 100 pounds, is shown in table 3.

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[4] Italic numbers in parentheses refer to Literature Cited, p. 1075.

TABLE 2.—*Average composition and total digestible nutrients of normal whole milk, colostrum milk, fresh skim milk, fresh buttermilk, fresh whey, dried skim milk, dried buttermilk, and condensed buttermilk* [1]

Milk product	Total dry matter	Mineral matter	Protein	Sugar or carbohydrates	Fat	Total digestible nutrients
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Normal whole milk	12.8	0.7	3.5	4.9	3.7	16.2
Colostrum milk	25.5	1.6	17.6	2.7	3.6	27.0
Fresh skim milk	9.6	.8	3.7	5.0	.1	8.6
Fresh buttermilk	91.6	.8	3.5	4.5	.6	9.1
Fresh whey (from American cheese)	6.6	.7	.9	5.0	.3	6.4
Fresh whey (skimmed)	6.6	.7	.9	5.0	.03	5.4
Dried skim milk	93.8	8.0	34.8	50.1	.9	84.1
Dried buttermilk	92.2	10.5	33.8	41.9	5.6	85.5
Condensed buttermilk	29.9	3.7	11.3	13.3	1.6	27.3

[1] Data from Feeds and Feeding (*819*), except for colostrum milk, which are from Missouri Research Bulletin 35 (*294*).

TABLE 3.—*Ratio of total digestible nutrients, and value for feed per 100 pounds of normal whole milk, fresh buttermilk, fresh whey, dried skim milk, dried buttermilk, and condensed buttermilk, compared to fresh skim milk* [1]

Milk product	Total digestible nutrients compared to fresh skim milk [1]		Value per 100 pounds for feed with fresh skim milk priced per 100 pounds at—				
			20 cents	30 cents	40 cents	50 cents	60 cents
	Percent	*Ratio*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
Fresh skim milk	8.6	1.00	0.20	0.30	0.40	0.50	0.60
Normal whole milk	16.2	1.88	.38	.56	.75	.94	1.13
Fresh buttermilk	9.1	1.08	.21	.32	.42	.53	.64
Fresh whey (from American cheese)	6.4	.71	.14	.21	.28	.36	.43
Fresh whey (skimmed)	5.4	.63	.13	.19	.25	.32	.38
Dried skim milk	84.1	9.78	1.96	2.93	3.91	4.89	5.86
Dried buttermilk	85.5	9.94	1.99	2.98	3.98	4.97	5.96
Condensed buttermilk	27.3	3.17	.63	.95	1.27	1.59	1.90

[1] Total digestible nutrients in feeds based on analyses from Feeds and Feeding (*819*), except for colostrum milk, which are from Missouri Research Bulletin 35 (*294*).

Where milk or milk products are not too high in cost, it is best to continue feeding them until the calf is about 6 months of age. By this time it should be eating large enough quantities of other feeds so that its growth will not be retarded to any appreciable extent.

When the cost of feeding milk or milk products is excessive, they may be gradually discontinued after the calf is 2 to 3 months old. Usually such calves will not gain so rapidly at this time as calves fed milk for 6 months.

Starting the Calf on Whole Milk

The proper feeding of the dairy calf during the first month is of the greatest importance. Since its digestive system is easily upset, it will thrive better at this time if it is fed sparingly rather than too much. In hand feeding, precautions are necessary that are not required when the calf takes its food in a natural manner.

It is essential that the calf get one or more good feedings of its mother's first milk or colostrum. Colostrum is much richer in protein, minerals, and vitamins, particularly vitamin A (*260*), than normal whole milk, and it has a laxative effect, cleaning out the meconium (first excretion from the bowels) so that the digestive system will start functioning properly. Colostrum also contains immunizing substances, called antibodies, which protect the young calf from commonly present harmful bacteria until it is able to establish its own natural resistance against them. Without this protection the calf may die from infections by bacteria that are not harmful to older animals (*758*). This subject is discussed at greater length in the article The Nutrition of Very Young Animals (p. 501).

The average strong, vigorous calf should be fed whole milk for at least 2 weeks; the whole milk may then be gradually replaced by fresh skim milk, other milk products, or special calf meals. If the calf is weak or is especially valuable, whole milk is usually fed for 3 or 4 weeks before making any change. During the first week the calf should get fresh warm milk from its dam. After that, warm mixed whole milk from the herd may be used. If the calf is weak, it may be desirable to feed small quantities of milk three times a day for a week or two, after which twice a day will be sufficient. Strong calves will usually do about as well if fed only twice a day from the start.

The quantity of whole milk to feed will depend on the size and condition of the calf. Too often the tendency is to feed too much milk at the start. As a consequence, the calf gets indigestion and scours and does not thrive as well as if it had received a smaller quantity. A safe rule to follow is never to feed strong, vigorous calves more than 1 pound of milk a day for each 10 pounds of live weight during the first 7 days.

The following quantities of milk per day will be sufficient at the start for average-sized, vigorous calves of the different breeds: Jersey, 5 pounds; Guernsey, 6 pounds; Ayrshire, 7 pounds; Holstein-Friesian and Brown Swiss, 8 pounds. (See table 1.) Large-sized, vigorous calves of these breeds may be safely fed 1 or 2 pounds more than the quantities indicated. Small calves and calves that are weak or sickly should receive smaller quantities according to their condition. If it is necessary to reduce considerably the quantity of milk fed, the calf may not get sufficient liquid to supply its needs for water. In such cases, enough warm water should be added to make up for the reduction in the quantity of milk. If the calf is well and there is no indication of scours during the first week, the quantity of whole milk fed may be increased by 1 or 2 pounds per day during the second week and by the same amount during the third week. No further increase in the total quantity of milk fed should be made while changing from whole milk to fresh skim milk or other liquid-milk products.

To avoid indigestion and scours, the calves should be fed at regular hours, and the milk should be weighed or measured at each feeding and fed at a temperature of 90° to 100° F. If the milk tests more than

4 percent of butterfat, it should be diluted with a little warm water or skim milk at each feeding. Until the calf is 3 or 4 weeks old, the addition of ½ to 1 cupful of warmed limewater to the whole milk at each feeding may be beneficial.

Feeding Fresh Skim Milk After Starting on Whole Milk

Fresh skim milk contains the protein, minerals, and carbohydrate of whole milk but lacks the milk fat and the fat-soluble vitamins A and D. Because of the high energy value of milk fat (2.25 times that of an equal quantity of carbohydrate) skim milk contains only a little more than half as much total digestible nutrients as normal whole milk (table 2). When it is supplemented by green, leafy, sun-cured hay, which provides vitamins A and D, and a suitable grain mixture to provide additional energy, calves will grow about as well on fresh skim milk as on whole milk.

If the young calf is vigorous, is digesting its feed properly, and has begun to eat small quantities of hay and grain, fresh skim milk can be gradually substituted for whole milk when the calf is 2 weeks old. Otherwise the change to skim milk should be delayed until the calf is 3 to 4 weeks old. Fresh, warm skim milk direct from the separator should be fed if possible. If not, it should be warmed to 100° F. before feeding. The change should be made gradually, substituting skim milk for whole milk at the rate of about 1 pound a day. To guard against digestive disturbances, the total quantity of milk fed should not be increased while this change is being made. If the calf has scours, any further substitution of skim milk for whole milk should be delayed until this condition disappears. If necessary, the calf should be given a purgative and the quantity of milk fed should be reduced.

After the change from whole milk to skim milk, the quantity of skim milk fed may be increased by 1 pound daily every week or by 2 pounds daily every 2 weeks until the calf is getting the maximum quantity it is to be fed. If skim milk is plentiful, Jersey, Guernsey, and Ayrshire calves should be fed from 12 to 14 pounds and Holstein and Brown Swiss calves from 14 to 16 pounds daily. These quantities of milk, with 3 pounds of grain daily and all the hay of good quality the calf will eat, will be sufficient for growth at about the rate shown in table 7 (p. 625). If hay is of the best quality and very palatable, the calf will eat more hay and can make normal gains to 6 months with the above quantities of milk and not more than 2 pounds of grain daily.

Where additional skim milk is available, large calves may be fed 18 to 20 pounds or even more to advantage (*1262*) and may be raised on a minimum amount of grain or with no grain at all. The calf getting no grain will not be so large nor appear so thrifty at 6 months (*292*, *568*, *953*) as the calf getting some grain. Where skim milk is scarce, calves may be raised on as little as 10 pounds daily (*885*, *993*, *995*). To obtain near normal growth to 6 months with this quantity of skim milk requires the feeding of at least 3 pounds of grain daily with good roughage, or 4 pounds daily with roughage of ordinary quality.

Usually the calf should be fed skim milk to at least 6 months of age. After the calf is 6 months old, it can grow and develop normally without milk. However, if additional skim milk is available and especially good growth is desired, calves may be fed skim milk to advantage up to 8, 10, or even 12 months of age (*995*).[5] Where skim milk is scarce, it may be discontinued as early as 2, 3, or 4 months of age (*240*) if the calf is fed roughage and all the grain it will eat up to 4 pounds daily between weaning time and 6 months of age. Calves receiving skim milk to only 50 or 60 days of age should be fed as outlined under limited-milk feeding (p. 608).

Starting the Calf Without Whole Milk

Though most authorities still recommend feeding whole milk for the first 2 or more weeks before changing to skim milk, the Bureau of Dairy Industry (*217*) has demonstrated that the main function of this whole milk is to supply vitamin A. Experiments showed that when late-cut brown timothy hay was fed so that milk was the main source of vitamin A, better growth was made by calves fed skim milk and cod-liver oil than by calves fed during the entire milk-feeding period on whole milk from cows on good winter rations. Later (*219*), calves were successfully reared when fed skim milk and cod-liver oil after the third day. To a very limited extent calves at the Bureau of Dairy Industry station at Beltsville, Md., have also been similarly fed after the third day with reconstituted skim milk made by mixing 1 part of skim-milk powder with 9 parts of water.

For several years most of the calves in the nutrition herd of the Bureau at Beltsville have received their dam's milk (colostrum) for 3 or 4 days and then have been changed abruptly to skim milk with cod-liver oil, carotene in oil, or grated garden carrots. Ten cubic centimeters (2 teaspoonfuls) of cod-liver oil, 15 milligrams of carotene in oil, or 180 grams (about 7 ounces) of grated yellow garden carrots fed in the skim milk have supplied sufficient vitamin A. These supplements have been safely omitted as soon as the calf was eating 1 or 2 pounds of fairly green hay—usually at 60 to 90 days of age. Holstein whole milk contains about twice the energy of skim milk. Since calves cannot safely be fed twice as much skim milk as the amount of whole milk recommended, the gains are usually not quite so high for the first month, but at later ages the calves do not show any disadvantage from being deprived of the customary whole milk. The calf shown in figure 3, *B* (p. 634) was fed by this method.

This practice is spreading in the United States and has recently been tried out in Scotland (*27*) where the growth rates of Holstein and Shorthorn calves fed as described compared favorably with those of similar calves reared on whole milk, with a saving of about $15 per animal.

Feeding the Calf Whole Milk

Whole milk is too expensive to feed to the calf in liberal quantities after it is 3 or 4 weeks old. However, where fresh skim milk is not available, it is often practical to feed whole milk in limited quantities to 7 or 9 weeks of age and raise the calf on a special dry-fed grain mixture containing some dried skim milk or other animal product. This method of feeding is discussed in detail under the heading Feeding Limited Quantities of Milk With Dry Grain or a Dry-Fed Calf Meal (p. 608).

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[5] Data will soon be available on feeding experiments with dairy heifers at field experiment stations of the Bureau of Dairy Industry.

Where dried-milk products are high in price, or where the calf is especially valuable, the feeding of whole milk in quantities not to exceed 8 or 10 pounds daily to 4 or even to 6 months of age may be justified. Fed whole milk at this rate, the calf should gain about as well as when fed to the same ages on more liberal quantities of skim milk. With the whole milk, the calf should receive all the green leafy hay it will eat, and up to 2 or 3 pounds of grain daily. Where whole-milk feeding is discontinued at 4 months of age, the quantity of grain fed should be increased to 4 pounds daily until the calf is about 6 months old.

Raising the Calf on a Nurse Cow

In many cases it may be practical to raise calves on a nurse cow if suitable cows are available to act as foster mothers (*94*). Hard milkers, low producers, low testers, cows with pendulous udders, or kicking cows may often be used to advantage for this purpose. One cow can nurse from two to four calves, depending on the quantity of milk being produced, and may raise several sets of calves during a lactation period.

Calves raised on a nurse cow are less trouble to feed, and if they do not get too little or too much milk, will thrive better than calves raised by other methods. The gains made by such calves will vary with the quantity of milk the calf gets by this method of feeding. Each calf should receive the first milk or colostrum from its dam before being placed on a nurse cow. The calf should not get too much milk at the start, and may be raised to about a normal weight on a maximum quantity of 8 to 10 pounds of milk a day. If the calf keeps in good condition and does not get scours from overeating, it may be assumed that it is properly nourished.

The calves are often allowed to run with the nurse cow. However, it is easier to regulate the feed of the cow and of the calves if they are kept in a separate pen or lot except at nursing time. Until the calves are between 1 and 2 months old, the cow should be turned in with them two or three times daily so that they can suckle, and then once a day until they are weaned.

When the calves are 2 weeks old they should have access to good hay, all they will eat of a dry-fed grain mixture or calf meal, and plenty of pure water. They may be weaned between 60 and 90 days of age and handled like any other calves being raised on grain or calf meals.

Feeding the Calf Fresh Buttermilk or Fresh Whey

If a creamery or cheese factory is located nearby, it may be possible to obtain fresh buttermilk or fresh whey for calf feeding. To be suitable for this purpose, buttermilk or whey should be strictly fresh and should not be diluted by wash water or to any appreciable extent by condensed steam. The product should also be pasteurized and hauled to the farm and fed while still fresh and wholesome. These products will not be desirable calf feeds except under these conditions.

Fresh buttermilk has practically the same composition as fresh skim milk but contains a small amount of fat. It is higher in acidity except possibly when sweet-cream butter is manufactured. If fresh buttermilk is of good quality and properly fed it will give about as good results as fresh skim milk (*885*). Fresh buttermilk may be somewhat more laxative than fresh skim milk, so that it will usually be best not to change from whole milk to this feed until the calf is 3 to 4 weeks old, and then the change should be made very gradually to avoid digestive disturbances. The quantities of fresh buttermilk to feed, the method of feeding, and supplementary feeds are the same as for fresh skim milk.

Fresh whey lacks not only the fat but also most of the protein contained in whole milk and has only about two-thirds of the feeding value of an equal weight of fresh skim milk. In addition it is somewhat laxative. When the whey is properly supplemented with legume hay of high quality and with a grain mixture high in protein, the calf will be thrifty and make a fairly good rate of growth on this feed (*885, 993*). For best results the calf should be given a good start on whole milk and not changed to fresh whey until it is 4 or 5 weeks old. The quantity fed should be gradually increased until the calf is receiving a maximum of 14 to 16 pounds daily. At the Wisconsin station (*993*), calves fed a maximum allowance of 14 pounds of fresh whey per day together with clover hay and a grain mixture consisting of 300 pounds of ground corn, 300 of standard wheat middlings, and 400 of linseed meal made an average gain of 1.48 pounds each daily compared with 1.52 for calves fed fresh skim milk limited to 10 pounds daily, and 1.76 for calves given a maximum of 14 pounds of fresh skim milk daily.

Feeding Reconstituted Dried Skim Milk, Dried Buttermilk, or Condensed Buttermilk

If fresh milk products cannot be obtained it is usually possible to purchase dried skim milk, dried buttermilk, or condensed buttermilk. These differ from the fresh products only in having most or part of the water removed through heating and evaporation. Because of the lower water content, approximately 1 pound of dried skim milk, 1 of dried buttermilk, or 3 pounds of condensed buttermilk have about the same feeding value as 10 pounds of the fresh products. Dried skim milk and dried buttermilk are shipped in either paper-lined barrels or bags and will keep indefinitely if stored in a dry place. In the production of condensed buttermilk, only part of the water is removed, leaving the material in a semisolid or heavy liquid form. This product is shipped in sealed barrels or cans, will keep indefinitely in the sealed container, and can be fed without loss from spoilage if an even layer is removed from the entire surface each day.

Feeding trials at a number of State agricultural experiment stations (*94, 685*) indicate that calves will grow nearly as well on dried skim milk or dried buttermilk reconstituted to the approximate composition of fresh skim milk or fresh buttermilk as they will on an equal weight of the fresh product. However, as a rule calves do not do quite so well on reconstituted semisolid buttermilk (*296, 993*) as on fresh or reconstituted dried skim milk or buttermilk. When the dried products can be obtained they are to be preferred to the semisolid products.

The calf may be fed the reconstituted dried skim milk beginning at 2 to 4 weeks of age, or sooner if a vitamin A supplement is fed.

The feeding of reconstituted dried or condensed buttermilk [illegible]d be delayed until the calf is 3 to 4 weeks old, as these feeds ma[illegible]omewhat more laxative than the dried skim milk. The change from whole milk to the reconstituted products should be made gradually, in the same way and with the same quantities as recommended for fresh skim milk. The method of feeding and supplementary feeds are the same as for fresh skim milk.

To prepare the dried skim milk or dried buttermilk for feeding, mix 1 part of the dried product to a smooth paste with an equal weight of warm water. When the lumps are all broken up, add 8 more parts by weight of warm water and stir thoroughly.

To prepare the condensed buttermilk for feeding, add 7 parts by weight of warm water to 3 parts of condensed buttermilk and stir until well mixed. For best results mix with the same proportion of water from day to day and feed at a temperature of about 95° F. Only enough should be mixed at one time for one feeding.

Where these products do not cost too much they may be fed in the same quantities as fresh skim milk until the calf is 4 to 6 months old. If the cost of such products is too high, the calf may be weaned at 7 to 9 weeks of age and placed on a good grain mixture or a good dry-fed calf meal containing dried skim milk or some other animal product.

If the calves have a tendency to scour, add one-half pint of limewater at each feed until this condition disappears. To make limewater, add 2 ounces of hydrated lime, or a lump of unslacked lime the size of an egg, to a pail of water. Allow the unslacked lime to slack. Stir vigorously. Allow the lime to settle and use only the clear solution.

Feeding Limited Quantities of Milk With Dry Grain or a Dry-Fed Calf Meal

Where skim milk or other milk products are scarce or high in price, the calf may be raised by feeding limited quantities of milk and gradually substituting a good grain mixture or calf meal for milk at an early age. Some calf meals are fed mixed with water in the form of a gruel. However, the calf may be raised with less labor and less trouble from scours if the meal is fed dry. Calves raised in this manner do not gain as rapidly or look quite as thrifty as calves fed liberal quantities of fresh skim milk, and they are sometimes difficult to raise. However, if given good care and attention and a good start on milk together with liberal quantities of hay and a good grain mixture or calf meal, they will make a satisfactory growth.

Experiments have indicated that calves may be raised on as little as 150 pounds of whole milk, including colostrum, with no milk after 30 days (*93*, *96*, *321*). However, taking milk away at this early age severely retards the growth of the calf for a while, since its digestive system has not developed to the point where it can digest large quantities of hay and grain. Feeding milk in limited quantities to 50 or 60 days gives the calves a better start, and they are eating larger quantities of hay and grain by the time milk feeding is eliminated. During this period the calf may be fed on whole milk or on whole milk and fresh or reconstituted skim milk, or it may be raised on a nurse cow (*94*, *240*, *296*). Not more than 325 to 400 pounds of whole milk or 150 to 200 pounds of whole milk and 400 to 600 pounds of skim milk will be required for this period of milk feeding. Small and weak calves require milk for a longer period and ordinarily should not be raised on limited milk feeding.

Grain as a Substitute for Milk

A grain mixture used as a substitute for milk should be composed of palatable feeds so that the calf will eat it readily. It should have a protein content of not less than 16 to 18 percent. Since the nutrients in grain are not so suitable for growth as the nutrients in milk, the growth of the calf will be retarded somewhat between 2 and 4 months of age. However, the calf will grow more rapidly from 4 months on and with good feeding may reach a normal weight when 6 months old or shortly thereafter.

At the Minnesota (*296*) and Missouri (*944*) Agricultural Experiment Stations, calves fed limited quantities of whole milk or whole milk and skim milk for 50 to 70 days together with alfalfa hay and a grain mixture consisting of 400 pounds of ground corn, 100 of wheat bran, and 100 of linseed meal (14.8-percent protein) failed by a considerable margin to attain normal weight at 6 months of age, but later reached normal size and were satisfactory breeding animals. Similar results were experienced at the Beltsville station of the Bureau of Dairy Industry [6] with calves fed a grain mixture with a protein content of 17.1 percent consisting of 200 pounds of ground corn, 200 of wheat bran, and 100 of linseed meal.

On the other hand, calves raised in a similar manner at several other State agricultural experiment stations, with either clover hay or mixed grass and legume hay for roughage, have attained a live weight at 6 months of age equal or nearly equal to the Ragsdale and Fohrman-Swett growth standards (see table 7, p. 625) on the following grain mixtures:

Wisconsin (*993*), protein 18 percent: Corn 25 percent, oats 25, wheat bran 25, linseed meal 25.

New Jersey (*93*), protein 17.6 percent: Corn 25 percent, oats 37.5, wheat bran 12.5, linseed meal 25.

Maryland (*96*) and Ohio (*240*), protein 16 percent: Corn 28.6 percent, oats 28.6, wheat bran 28.6, linseed meal 14.2.

South Carolina (*321*), protein 17.3 percent: Corn 40 percent, oats 40, cottonseed meal (41-percent protein) 20.

Calf Meals as Substitutes for Milk

Dry-fed calf meals or calf starters consist of a good grain mixture with the addition of protein from some animal source. The protein content is 20 percent or more. On a good calf meal the calf as a rule will maintain a better rate of growth following weaning from milk than on an ordinary grain mixture. With good feeding, calves should be normal or a little above average in weight at 6 months, and on a special calf starter may be considerably above average.

Animal products that have been used in calf meals include dried skim milk, dried buttermilk, soluble blood flour, ordinary blood meal, dry-rendered tankage, and fish meal. Dried skim milk provides the best possible source of animal protein for the calf and has given good results in many calf meals. Twenty to twenty-five percent of this product in a calf meal will give about as good results as larger quantities (*95, 1012*). Dried buttermilk (*567*) that is of uniformly good quality and not too acid may also be used, but it may not give quite as good results as dried skim milk.

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[6] Unpublished reports of experiments by H. T. Converse on the feeding of limited milk and grain to dairy calves.

Soluble blood meal or flour, rather unpalatable products, have been used to the extent of 12.5 percent of a calf meal as the sole source of animal protein at the New Jersey (*93*) and several other State agricultural experiment stations. When the calf can be induced to consume in large enough quantities a meal containing one of these products, it will grow about as well as on one containing dried skim milk. However, some calves do not eat readily a calf meal containing soluble blood flour and as a result do not grow so fast nor look quite as thrifty as calves fed a calf meal containing dried skim milk. In a recent feeding trial at the Ohio Agricultural Experiment Station (*648*) ordinary blood meal and dry-rendered tankage, constituting 12.5 percent of a calf meal, gave about as good results as 12.5 percent either of soluble blood flour or of dried skim milk.

Fish meal is made from several kinds of fish residues. Used as the sole source of animal protein, 12.5 percent of fish meal gave as good results as 12.5 percent either of soluble blood flour or of dried skim milk at the Ohio station. However, calves did not make satisfactory growth at the New Jersey station (*63*) on a calf meal containing 12.5 percent of fish meal, nor at the South Carolina station (*321*) on one containing 15 percent of fish meal. Used to the extent of 10 percent of the calf meal to supplement or partially replace dried skim milk, fish meal has proved satisfactory at the Maryland (*96*) and New York (Cornell) (*1012*) stations, but gave unsatisfactory results at the South Carolina station. Only the best grades of fish meal, processed from fresh fish residues into a wholesome product low in moisture and fat, are suitable for calf feeding.

As a rule, such products as fish meal, dried blood flour, blood meal, and dry-rendered tankage are better suited to supplement dried skim milk in a calf meal than for use as the sole source of animal protein.

The following calf meal, composed of easily obtainable ingredients, is not very different in composition from calf meals containing dried skim milk on which calves have attained a size at 6 months equivalent to the Ragsdale and Fohrman-Swett growth standards at several State agricultural experiment stations:

	Percent		*Percent*
Ground yellow corn	30	Linseed meal	10
Crushed or rolled oats	30	Dried skim milk	20
Wheat bran	10		

The ingredients used in this mixture may be varied somewhat to meet conditions on individual farms. Oatmeal without the hulls will give a little better results than ordinary oats. White corn will be about as good as yellow corn. Ground or rolled barley may be used to replace part or all of the ground corn. Ten percent of soybean meal, cottonseed meal (41- or 43-percent protein), dried blood flour, or a high-grade fish meal may be used to replace the linseed meal or half of the dried skim milk.

At the South Carolina Agricultural Experiment Station (*321*), calves made slightly better than normal growth to 6 months on a simple calf meal consisting of 35 percent of ground yellow corn, 35 of ground oats, 20 of cottonseed meal (41-percent protein), and 10 of dried skim milk.

From 0.5 to 1 percent of salt should be added to grain mixtures and calf meals. Finely ground steamed bonemeal and ground limestone are also added to some calf meals at the same rate. These may be helpful if the hay fed is not a legume or is not of the best quality.

At the New York (Cornell) Agricultural Experiment Station, Savage and Crawford (*1012*) found that a good calf meal containing 20 percent of dried skim milk gave better results when small quantities of whitefish meal and cod-liver oil were added in addition to the minerals. This calf meal, called a reinforced calf starter, is as follows:

	Percent		*Percent*
Ground yellow corn	32. 25	Dried skim milk	20. 00
Rolled oats (oatmeal)	28. 00	Salt	. 50
Wheat bran	10. 00	Ground limestone	. 50
Linseed meal	5. 00	Steamed bonemeal	. 50
Whitefish meal	3. 00	Fortified cod-liver oil	. 25

In the above mixture, 0.5 to 1 percent of ordinary animal-feeding cod-liver oil may be substituted for the fortified cod-liver oil. In grain mixtures of this kind, cod-liver oil is known to lose most of its vitamin A potency within a short time, and the best way to supply cod-liver oil is to mix 2 to 4 teaspoonfuls in the feed of each calf every day.

Recently Newman and Savage (*852*) at the New York (Cornell) station have found that the addition of either dried brewers' yeast or a cereal yeast feed to a dry calf starter resulted in a more rapid growth of the calf with a little lower total digestible nutrient requirement per unit of gain in weight. Six percent of dried brewers' yeast used to supplement 20 percent of dried skim milk, or 5 percent of cereal yeast feed and 5 of soybean meal, used to replace half of the dried skim milk, gave nearly as good results as when a 16-percent cereal yeast feed was used to replace half of the dried skim milk. This increased efficiency of the calf meal was thought to be due to the vitamin B factor in the yeast. However, yeast feeding has been found not to be beneficial for young calves being fed fresh milk in normal quantities, or for older calves.

There are several ready-mixed calf meals or calf starters on the market. The best contain one or more animal products and give about as good results as a good home-mixed calf meal. Some of these have been compressed into pellet form. In a feeding experiment reported by Newman and Savage (*852*) calves fed a calf meal in pellet form did not make any better growth than calves fed the same meal in the usual ground form.

Directions for Feeding Calf Meals

The following directions for feeding apply to both commercial calf meals and home-mixed grain and calf meals. They are made on the basis of feeding limited quantities of milk until the calf is 7 to 9 weeks old. Warm water is added as the quantity of milk is decreased so that the calves will not suffer from a lack of water until they are accustomed to drinking from the regular supply.

Limited whole milk:	Whole milk (pounds per day)	Warm water (pounds per day)
Holstein and Brown Swiss:		
First week	8	----
Second week	9	----
Third week	10	----
Fourth week	8	2
Fifth week	6	4
Sixth week	4	6
Seventh week	2	8
Ayreshire, Jersey, and Guernsey:		
First week	6	----
Second week	7	----
Third to sixth weeks	8	----
Seventh week	6	2
Eighth week	4	4
Ninth week	2	6

Limited whole milk and skim milk: Feed whole milk as indicated above for the first 2 weeks and change from whole milk to skim milk during the third week. Increase the quantity of skim milk fed by 2 pounds daily each week until the calf is getting 12 pounds daily. Reduce the quantity of skim milk fed by 3 pounds a day each week during the fifth, sixth, and seventh weeks for Holstein and Brown Swiss calves, and during the seventh, eighth, and ninth weeks for Ayrshire, Jersey, and Guernsey calves, substituting warm water in the same way as above.

Calves raised on nurse cows: Regulate the number of calves on a nurse cow so that each calf is getting from 6 to 8 pounds of milk daily. Allow the calves to suckle twice daily for the first 4 to 6 weeks, then once daily for 3 weeks until weaned.

Feed each calf milk according to its size and condition, for a shorter or longer time as conditions warrant. Provide a convenient, abundant supply of pure water so that the calf will become accustomed to obtaining its own supply before the quantity of milk fed is reduced.

When the calf is 10 days old, offer it both hay and grain. Use the best quality hay on hand, preferably a legume. Early-cut grass or mixed grass and legume hay are also suitable. Give the calf all the hay it will eat at all times and all the grain or calf meal it will eat up to 4 or 5 pounds daily. When the calf is 3 months old, the calf meal can be gradually discontinued and a cheaper grain mixture fed instead so that at 4 months of age the calf is getting all grain. Feed 4 to 5 pounds of grain daily until the calf is 6 months old.

When the calf is weaned from milk at 50 to 60 days, it should be eating 1½ to 2 pounds of grain or calf meal daily; at 3 months, 3 to 4 pounds daily; and at 4 months, 4 to 5 pounds daily. The total quantity of grain or calf meal and grain required to 6 months of age on this basis is about 400 pounds per head for Jerseys and 500 pounds for Holsteins. When a calf meal is fed it will constitute approximately half of the grain.

The amount of hay consumed will depend on its palatability and also on the quantity of calf meal and grain fed. With hay of good quality and the above quantities of calf meal and grain, the calf may be expected to consume nearly as much hay as grain from weaning time to 4 months of age, and somewhat more hay than grain between 4 and 6 months of age, with a total hay consumption of between 400 and 450 pounds of hay by Jerseys and 500 to 600 pounds by Holsteins. With especially palatable hay, heifers may consume somewhat more than this.

Feeding Hay

In order to grow and develop normally the calf requires hay and grain at an early age to supplement milk. These should be fed as soon as the calf can be induced to eat them, usually at about 10 days to 2 weeks of age. A handful of the most palatable hay on hand should be placed in a rack where the calf can reach it conveniently but cannot soil it. Until the calf is eating hay readily, a fresh supply should be provided each day in order to tempt its appetite.

Hay used for feeding young calves should be cut before it gets too mature and handled during curing so as to retain as much of its green color and leaves as possible. Such hay will be high in protein, assimilable minerals—particularly calcium—and vitamin A. Sun-cured hay will also be a good source of vitamin D, while artificially dried hay will be low in this vitamin. Legume hays (alfalfa, clover, soybean, cowpea, etc.) or grass hays cut before the blossom stage (timothy, prairie, a pasture-grass mixture, etc.) will usually be highest in these constituents and the most suitable for calf feeding. The calf will thrive on sun-cured hay that has a nice green color, but with hay that has lost its green color a vitamin A supplement will be required. The calf can also be fed principally on artificially dried hay if it gets plenty of sunshine and is fed a little sun-cured hay; otherwise a vitamin D supplement will be required.

The calf should be fed at all times as much good-quality hay as it will eat. Where alfalfa hay is fed, the calf should not be given hay that is unusually leafy and palatable during the first few weeks, as calves will sometimes overeat on such hay and get indigestion and scours. The quantity of hay consumed will depend not only on its palatability but also on the quantity of other feeds consumed. Ordinarily the calf will be eating 1 pound of hay or a little more daily at 2 months of age, 2½ to 3 pounds daily at 3 months, and 5 to 6 pounds daily at 6 months of age. When the hay is especially palatable, or the quantity of grain fed along with milk is limited to 2 or 3 pounds or less daily, or the calf is being raised on grain or grain and a calf meal without any milk, the calf may consume larger quantities than this at 6 months of age (*1222*). Headley[7] of the Nevada Agricultural Experiment Station reported a hay consumption of 13 pounds per head daily at 6 months by Holstein heifers fed skim milk with one-half pound of grain daily and all the good alfalfa hay they could eat from an outside rack.

Feeding Grain

The calf can be taught to eat grain when 10 days to 2 weeks old by rubbing a little on its muzzle and placing a small handful in the bottom of the pail after it has finished drinking its milk. The grain fed to dairy calves should be palatable and provide the energy, protein, and minerals required for normal growth that are not provided in the milk and hay. The farm grains (corn, oats, barley, kafir, and milo) and the protein concentrates (wheat bran, linseed meal, and soybean meal) are all suitable feeds for the young calf. Cottonseed meal may also be fed in limited quantities The protein concentrates contain more minerals as well as more protein than the farm grains. Wheat bran and linseed meal are particularly good sources of phosphorus.

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[7] HEADLEY, F. B. HAY CONSUMPTION BY HEIFER CALVES. Nev. Agr. Expt. Sta. News Bull., v. 7, No. 1. 1933. [Mimeographed.]

The percentage of protein needed in the grain mixture will depend on the ration fed. When the calf is getting moderate or liberal quantities of skim milk or buttermilk along with a leafy legume hay or early-cut grass or mixed hay the grain fed can consist entirely of farm grains and the calf will make as good or nearly as good growth as where wheat bran and linseed meal are included in the grain mixture (*570*, *885*). A grain mixture containing 14 to 16 percent of total protein may be needed by calves fed limited quantities of skim milk or buttermilk with good hay. A grain mixture containing as much as 18 to 20 percent of total protein may be required by calves fed whey or those fed grain as a substitute for milk, with good hay. Where the hay and grain are home grown and the soils of the locality are known to be low in phosphorus, it is best to include wheat bran or 1 percent by weight of bonemeal in such a mixture. Suitable grain mixtures are shown in table 4.

Table 4.—*Grain mixtures for young dairy stock containing specified percentages of protein*

Grain or concentrate	Mixtures containing 10 to 12 percent of total protein [1]				Mixtures containing 14 to 16 percent of total protein [2]				Mixtures containing 18 to 20 percent of total protein [3]			
	A	B	C	D	E	F	G	H	I	J	K	L
	Lb.	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*
Corn	(4)	10	30	20	20	30	30	30	10	20	10	20
Oats	(4)	10	----	20	20	--	10	30	20	------	10	20
Wheat bran	------	------	10	10	---	10	10	30	------	10	10	10
Linseed meal	------	---	------		10	10	10	10	10	10	10	20

[1] Suitable for calves under 6 months fed 12 to 14 pounds or more daily of milk or some milk product other than whey with good hay (leafy legume hay, early-cut grass or mixed hay); also for heifers and bulls over 6 months fed good hay or such hay and grass or legume silage.

[2] Suitable for calves under 6 months fed not over 10 pounds daily of milk or some milk product other than whey, with good hay; also for heifers and bulls over 6 months fed (1) good hay (leafy legume hay, early-cut grass or mixed hay) with corn, kafir, or sorghum silage, or fodder; or (2) poor hay (made from mature grass or from legumes that are very mature and have undergone shattering), or corn, kafir, or sorghum fodder with grass or legume silage.

[3] Suitable for calves under 6 months fed whey or those fed grain as a substitute for milk, with good hay; also for heifers and bulls over 6 months fed poor hay (made from mature grass or from legumes that are very mature and have undergone shattering), or such hay with corn, kafir, or sorghum silage or fodder.

[4] Corn alone or oats alone.

In the grain mixtures given in table 4, barley, kafir, milo, or hominy feed may replace part or all of the corn; soybean meal may replace part or all of the linseed meal. Cottonseed meal may replace one-half of the linseed meal until the calf is 6 months old, and either half or all of the linseed meal for older calves. Young calves seem to prefer whole corn or oats to ground corn or oats at first, and they do about as well up to 4 or 5 months of age on the whole grain (*516*). After the calf is 4 or 5 months old, the corn should be ground and the oats either ground or rolled. Kafir and milo should be ground and barley either ground or rolled for calves of all ages.

A calf 2 weeks old will eat only a small handful of grain a day. Calves being fed liberal quantities of milk will eat about half a pound daily at 4 weeks, 1 pound at 6 weeks, 1½ pounds at 8 weeks, and 2 pounds at 10 weeks to 3 months of age. This will be enough grain if milk is fed liberally to 6 months of age along with the best quality legume or mixed hay. When milk is fed in limited quantities or discontinued at an earlier age, or a poor grade of hay is fed, it may be necessary to feed 3, 4, or even 5 pounds of grain a day, including a calf meal.

Feeding Silage

Silage is not a suitable feed for the young calf (*1209*). The addition of this feed to the ration is apt to cause digestive disturbances and scours. Furthermore, it is desirable that the calf eat as much hay as possible during the first 3 months. After that, however, silage makes a desirable feed to supplement hay. Corn, kafir, or sorghum silage, or silage made from pasture or hay crops, may be fed.

Silage made from corn, kafir, sorghum, and grasses that are nearing maturity is low in protein, while that made from legumes and from grasses cut while still immature is high in protein. Corn silage contains essential amino acids that may be lacking in some hay crops and is a particularly desirable feed for supplementing alfalfa and other legume hays. If the plant material is put in the silo while green and not more than slightly wilted, the silage will be a good source of vitamin A to supplement poor hay. Silage of all kinds is low in vitamin D.

When the calf is 3 months old, it can be fed 1 or 2 pounds of silage a day. By the time it is 4 or 5 months old, it can be fed 1 pound of silage a day for each month of its age, or 2 pounds of silage a day for each 100 pounds of live weight. Care should be taken not to feed any moldy or frozen silage, and any uneaten silage should be removed from the manger each day.

Pasturage for the Calf

Pasturage is one of the best of feeds for the growing calf. However, the young calf will consume very little pasturage in addition to milk, hay, and grain, and young calves will do better in hot weather when kept in cool, well-ventilated quarters during the day than when allowed to run in a pasture or open lot in the sun. The calf will be able to make better use of pasturage after it is 3 months old provided the grass is abundant and the weather is not too hot.

The pasturage provided for calves and heifers should be the best available, preferably consisting of immature, rapidly growing grasses and clover. Such pasturage is low in crude fiber and high in easily assimilable protein, carbohydrates, minerals, and vitamins (except vitamin D, which the calf gets from sunshine) and furnishes a well-balanced feed for body maintenance and bone and muscle building.

Fall and early winter calves will make good growth the following spring and summer on pasture supplemented by skim milk and grain, or by grain alone when they are 4 to 6 months old. Spring calves will not be old enough to make much use of pasture until late in the summer and during the fall. Because pastures are often poor at this season, it is best to keep spring and summer calves off pasture, except for exercise, until the following summer.

RAISING THE DAIRY HEIFER

Feeding Heifers From 6 Months to 2 Years of Age

By the time the heifer is 6 months old the feeding of skim milk or special calf meals has been discontinued. At this age it is still growing rapidly but can make good growth largely on roughage feeds of good quality, supplemented by a little grain. By the time the heifer is a year old, it is usually past the period of maximum gains, can consume more roughage, and can make normal growth with still less grain. Plenty of good roughage should be supplied at all times in the form of good pasture in summer and hay or hay and silage in winter. Fodder may be used to provide part of the roughage for heifers over 1 year of age.

During the grazing season the heifer should be provided with good pasturage when available (fig. 2). Except on irrigated land, permanent pasture may not furnish all the roughage the animals should have throughout the grazing season. When available, the second growth on a hayfield after cutting for hay or crops such as rye and vetch, oats and peas, Sudan grass, soybeans, Italian ryegrass, and sweetclover may be used as temporary pasture to supplement poor permanent pasturage (pasture with short, scanty growth). When temporary pastures are not available, heifers may be fed hay or hay and silage while on early spring pasture or poor summer pasture. If there is plenty of good hay on hand, it would be well to keep a supply available at all times throughout the grazing season, in a conveniently located rack so that the heifer can eat it at will.

Figure 2.—**Pasture should provide good grazing and if possible shade and water also.**

When pastures are at their best, with grass immature and abundant, or when poor pastures are supplemented by all the good-quality hay or hay and silage the animals will eat, heifers 6 to 9 months of age will not require more than 3 pounds of grain a day, and heifers over 9 months old will not need any grain. On the other hand, if a limited quantity of good roughage is fed with poor pasture, or the roughage fed with such pasture is poor in quality and unpalatable, it may be necessary to feed heifers 6 to 9 months old 5 pounds of grain, and older heifers 3 to 5 pounds, per head daily in order to maintain growth at a normal rate.

During the winter season, the heifer should be fed so that it will make about normal growth but will not get too fat. Heifers in a high state of flesh make smaller than normal gains when they go out on pasture in the spring (*503*). As a rule, the growing heifer should be supplied with all the hay it will eat at all times. The hay fed may be either legume, mixed grass and legume, or grass hay. It should preferably be early-cut, fine-stemmed, and leafy, and grade not less than U. S. No. 2 for green color. Heifers over 1 year of age may receive part of their roughage in the form of corn, kafir, or sorghum fodder, if it has a good bright color. If silage is available, it may be fed to replace part of the dry roughage. Corn, kafir, or sorghum silage makes a good feed to supplement legume, mixed, or grass hays. Grass or legume silage makes a good feed to supplement mixed or grass hays, or corn, kafir, or sorghum fodder. If the hay or fodder is a good green color and is readily consumed in large quantities, 2 pounds of silage per 100 pounds of live weight daily is enough to feed the growing heifer. If the hay or fodder is of only ordinary or poor quality, the quantity of dry roughage may be reduced to 4 or 5 pounds per head daily and the heifer fed in addition all the silage that it will consume.

When fed all the roughage it will consume, the heifer 6 to 9 months old will need about 3 pounds of grain daily along with roughage of good quality, and 5 pounds of grain daily with roughage of only ordinary quality. Heifers more than 9 months old will not require any grain with good hay and silage, but may need 2 to 3 pounds daily with good legume hay or with silage and ordinary hay, and as much as 5 pounds of grain daily with ordinary hay or with such hay and corn, kafir, or sorghum fodder. In some irrigated sections of the West, heifers allowed free access to a good quality of alfalfa hay, so that they can eat all they want at all times without consuming the coarse stems, have made normal or near normal growth from birth on skim milk and alfalfa hay without any grain or with only very limited quantities of grain. Headley of the Nevada Agricultural Experiment Station reported[8] a live weight at 12 months of age of 650 pounds for Holstein heifers fed this ration with only one-half of a pound of grain daily from birth to 6 months of age. These heifers were kept in a separate lot and were fed alfalfa hay from an outside rack. All hay was weighed. Hay consumption amounted to 13 pounds per head daily at 6 months of age, 19.5 pounds at 9 months, and 26 pounds at 12 months.

The ration will contain plenty of protein if grain containing 10 to 12 percent of protein is fed along with immature, abundant pasture, leafy legume hay or early-cut mixed or grass hay, or with such hays and grass or legume silage. The grain should contain 14 to 16 percent of protein with ordinary and less abundant pasturage, with good hays and corn, kafir or sorghum silage, or with poor hay made from mature grass or from legumes that were very mature and have undergone considerable shattering, or with such hay and grass or legume silage; and it should contain 18 to 20 percent of protein with poor hay alone or with such hay and corn, kafir, or sorghum silage. Suitable grains and grain mixtures for feeding heifers are listed in table 4 (p. 614).

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[8] In the mimeographed bulletin cited in footnote 7, p. 613.

The approximate quantities of feed required by the heifer at different ages for normal growth in terms of grain and good hay or its equivalent are given in table 1 (p. 599). The basis on which these quantities were calculated is shown at the bottom of the table. Feed substitutions to fit the ration and quality of feeds being fed may be made on the following basis: 3 pounds of silage (made with little or no wilting), 5½ of carrots or rutabagas, 6 of turnips, 7 of mangels, 2 of sweetpotatoes, 2 of fodder (including uneaten portion), or 0.7 of grain may be substituted for 1 of good hay; 1½ of hay, 3 of fodder, 4½ of silage, 8 of carrots or rutabagas, 9 of turnips, 10 of mangels, 3 of sweetpotatoes, or 9 of fresh skim milk are equal in feeding value to 1 pound of grain.

Feeding the Heifer Before and After Calving

The heifer should be making good growth and be in good flesh at calving time; otherwise she may not give as much milk as she should after calving or grow at a satisfactory rate during her first milking period. On the other hand, she should not be excessively fat, as this will not make her a better milk cow and may result in calving difficulties and congestion of the udder.

If at 3 or 4 months prior to calving the heifer is growing at about a normal rate and is well fleshed, the ration being fed may be continued until near calving time without increasing the quantity of grain. If the heifer is in fair flesh, 4 or 5 pounds of grain a day will be sufficient to feed along with liberal quantities of good roughage. If she is somewhat thin or if the roughage is not of the best quality, it may be necessary to feed 6 to 8 pounds of grain a day in order to have her in good flesh by calving time. The grain mixture should contain enough protein to balance the roughage fed. (See table 4, p. 614.) Several weeks before calving, ground oats, wheat bran, and linseed meal are especially desirable feeds to include in the grain mixture. As calving time approaches, the heifer should have only moderate quantities of hay and silage, and the drinking water should not be too cold.

After calving, the heifer should be fed sparingly for a few days in order to help prevent digestive disorders and reduce the swelling in the udder to a minimum. She should have warm water to drink after calving, and a little good hay as soon as she cares to eat it. The second day she may be fed hay, a little silage, and 4 pounds of grain. Roughage may then be fed in as large quantities as the heifer will consume it, and the grain may be increased gradually until she is on full feed 3 to 4 weeks after calving. From this time on throughout the first lactation period, the heifer should be fed total nutrients and protein for maintenance and milk production in the quantities called for by a feeding standard such as those discussed in the articles on dairy cattle feeding in this Yearbook, or in Farmers' Bulletin 1626, Feeding Dairy Cows (*1265*). In addition, the heifer should be provided enough nutrients above these requirements to enable her to continue to make normal growth during the first lactation period.

Heifers that are undersized at first calving because of underfeeding or calving at too early an age may, if properly fed during the first lactation, gain in weight as much as 125 to 150 pounds between first and second calvings, exclusive of the increased weight due to gestation or differences in weight due to differences in degree of fleshing at calving time. On the other hand, heifers that are large at first calving because of liberal feeding or delayed calving may not gain more than 50 to 75 pounds in weight during this period.

As a rule, it will be well to provide additional nutrients for at least 100 pounds of gain in live weight, and if the heifer is considerably undersized at first calving, for as much as 150 pounds of gain during the first lactation period. It is probable that at this age as much as 3 pounds of digestible nutrients will be required to produce 1 pound of gain in live weight in the animal, or a total of 300 to 450 pounds of total digestible nutrients. These quantities of nutrients will be provided by 400 to 600 pounds of grain or 600 to 900 pounds of hay. Spread out over a 10-month period beginning at 60 to 90 days after calving the daily quantity of feed required for growth would be equivalent to 1⅓ to 2 pounds of grain or 2 to 3 pounds of hay.

The Relation of the Ration and Age at First Calving to Growth and Production of Dairy Heifers

The methods of feeding dairy calves and heifers that have been outlined provide sufficient nutrients for growth at about the rate shown by the Ragsdale and Fohrman-Swett growth standards (table 7, p. 625). Some breeders feed an extra-liberal ration in order to raise heifers above normal in size. On the other hand, many heifers are fed such scanty rations that their rate of growth is considerably retarded. The time of breeding for first calving will depend on the rate of growth and size of the heifer rather than on age.

The rate at which a calf grows and the mature size it may attain depend upon its inheritance, health, and nutrition. Disease or underfeeding will retard growth and may cause the animal to fail to reach its mature size at the usual age. If the disease is severe enough or underfeeding is continued long enough, the animal may be permanently stunted. Liberal feeding, on the other hand, will accelerate the growth rate, and the animal may reach breeding age and mature size a little earlier than usual.

Calves may be fed only medium amounts of feed and allowed to reach calving size in, say, 30 months, or they may be fed more heavily and be large enough to calve at 24 months. Slow growth requires more feed per unit of gain because of the greater proportion of nutrients used for maintenance. On the other hand slow growth can be made on rations made up of rougher and cheaper feeds. In this discussion, it has been assumed that heifers will be sufficiently well grown to calve at 2 years to 2 years and 3 months of age, although there may be conditions under which slower growth is more economical.

The influence of scanty and liberal rations and of age at first calving on the growth and production of dairy heifers have been investigated by Eckles (*292*) at Missouri, and by Reed, Fitch, and Cave (*953*) at Kansas. Eckles raised Jersey and Holstein heifers on an extra-liberal ration to first calving. This ration consisted of whole milk, liberally fed to 6 months, with all the alfalfa hay and grain the animals would eat. The heifers were above normal in weight from birth to the time of first calving. After calving, these heifers were fed a normal, good dairy ration consisting of alfalfa hay, corn silage, and grain according to production. Their growth then slowed down to somewhat below normal for age, and at 5 years of age their height at withers was just about normal (table 5).

TABLE 5.—*Effect of the ration on the growth of dairy heifers*

LIVE WEIGHT

Age	Eckles[1]				Reed, Fitch, and Cave[2]		
	Jersey		Holstein		Holstein		
	Skim milk[3] and alfalfa hay	Whole milk,[3] alfalfa hay, and grain	Skim milk[3] and alfalfa hay	Whole milk,[3] alfalfa hay, and grain	Skim milk[3] and alfalfa hay	Skim milk,[3] alfalfa hay, and corn silage	Skim milk,[3] alfalfa hay, corn silage, and grain
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Birth	53	50	94	83	88	86	87
6 months	252	298	317	422	322	306	346
12 months	371	495	432	664	430	443	565
18 months	495	722	598	912	560	644	800
24 months	607	827	731	1,110	767	802	1,015
After first calving	656	879	855	1,053	859	935	1,055
After second calving	734	863	956	1,050	976	1,077	1,112
After third calving	835	928	1,081	1,142	[4] 1,059	[4] 1,156	[4] 1,250
After fourth calving	875	941	1,149	1,261			

HEIGHT AT WITHERS

Age	Eckles[1] Jersey, Skim milk and alfalfa hay	Eckles[1] Jersey, Whole milk, alfalfa hay, and grain	Eckles[1] Holstein, Skim milk and alfalfa hay	Eckles[1] Holstein, Whole milk, alfalfa hay, and grain	Reed, Fitch, and Cave[2] Holstein, Skim milk and alfalfa hay	Reed, Fitch, and Cave[2] Holstein, Skim milk, alfalfa hay, and corn silage	Reed, Fitch, and Cave[2] Holstein, Skim milk, alfalfa hay, corn silage, and grain
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Birth (or 1 month)	27.6	27.4	30.3	30.7	30.1	30.5	30.3
6 months	35.2	36.4	38.6	41.1	38.7	38.6	39.6
12 months	40.5	42.9	42.2	46.3	42.0	42.8	44.8
18 months	43.3	46.5	45.7	49.6	45.8	46.7	48.7
24 months	45.5	47.8	48.4	51.2	48.2	49.2	50.6
36 months	47.7	49.2	50.4	52.6	49.9	51.3	52.3
48 months	48.3	49.4	51.4	53.1	50.9	52.2	53.4
60 months	48.2	49.4	52.1	53.4	51.3	52.5	53.2

[1] Light and heavy rations fed to first calving. After first calving all heifers received a normal ration consisting of alfalfa hay, corn silage with grain according to milk production (corn 4, bran 2, linseed meal 1) (*292*).

[2] Fed the same ration before first calving and through the first and second lactations (*953*).

[3] Whole milk fed first 2 to 4 weeks on all rations. No milk fed after 6 months of age.

[4] Weights taken at 60 months of age, or at end of second lactation.

Reed, Fitch, and Cave raised Holstein heifers on a ration consisting of whole milk to 1 month, skim milk to 6 months, alfalfa hay, corn silage, and grain. The heifers were fed the same ration during the first two lactation periods. These heifers were slightly below normal in weight and in height at withers at 2 years of age. After calving, their growth continued at a normal or slightly above normal rate, and at 5 years of age, their height at withers was approximately normal (table 5).

Eckles raised Jersey and Holstein heifers, and Reed, Fitch, and Cave raised Holstein heifers to first calving on a light or scanty ration. The ration fed in both cases consisted of whole milk to 2 or 4 weeks, skim milk to 6 months, and alfalfa hay. Some of the Missouri heifers also received a little pasture. Both the Missouri and Kansas heifers grew at a considerably retarded rate and were considerably below normal in weight and height at withers from birth to 2 years of age (table 5). Following calving, the Missouri heifers received a good ration consisting of alfalfa hay, corn silage, and grain, and were able partly to make up this growth shortage by growing at a slightly accelerated rate from first calving to 5 years. The Kansas heifers, on the other hand, continued to receive a scanty ration during the first two lactations and were considerably below normal in height at withers at 5 years of age.

Reed, Fitch, and Cave also raised Holstein heifers on a ration that was intermediate between light and liberal. This ration consisted of whole milk to 1 month, skim milk to 6 months, alfalfa hay, and corn silage. The same ration was fed during the first two lactation periods. The heifers were intermediate in weight and in height at withers between the lightly and liberally fed groups at both 2 and 5 years of age (table 5).

The average age of the heifers on the different rations at the first estrus (heat) period as noted by Eckles for the Missouri heifers was about 9 months on the liberal ration and 12 months on the light ration.

Eckles' data showed that gestation had very little effect on the growth rate of dairy heifers, but that after calving heifers grew at a considerably slower rate than pregnant heifers of the same age. A combination of heavy feeding and late first calving (over 30 months of age) was found to produce the largest heifers. Heavily fed heifers that calved early (from less than 2 years to about 27 months of age) did not reach quite the size at maturity as those calving later. Lightly fed, late-calving heifers attained about the same size at maturity as heavily fed, early-calving heifers. On the other hand, lightly fed, early-calving heifers were considerably below normal in size at maturity. A combination of scanty feeding and early calving was considered by Eckles to be the cause of many of the undersized cows found in dairy herds. Such cows undoubtedly produce somewhat less milk and butterfat at maturity than they would have if raised to a normal size. However, Eckles as well as Reed and his coworkers found that, considering their size, cows raised on scanty rations produced just about as well later on when fed liberal rations as cows raised from birth on liberal rations.

Turner (*1153*) studied the influence of age at first calving on milk production during the first lactation of large numbers of Ayrshire, Guernsey, Holstein, and Jersey cows on yearly Advanced Registry or Register of Merit tests. He found that as age at first calving increased, up to about 36 months, there was an increase in milk and butterfat production with age, in quantities that seemed to be closely correlated with the growth or increase in size of the animal. The increase in production was found to be very small between 30 and 36 months of age, and the heifers produced only 5 to 10 percent less than the maximum quantity of milk when calving for the first time at 23 to 28 months of age.

Data by Eckles (*292*) for Jersey and Holstein cows, and by Beam (*72*) of the Pennsylvania Agricultural Experiment Station for Guernsey cows, show that as the age at first calving increased up to about 36 months, the average butterfat production per lactation for the first 3 lactations (Eckles) and 5 lactations (Beam) also increased slightly. On the other hand, data by Chapman and Dickerson (*199*), which are presented in table 6 and which include 253 Holstein cows, each with 5 lactations, on 40 Wisconsin farms, show that the butterfat that the heifers would have produced if milking, at any calving age from 22 to 23 months of age or older, would have more than offset the increased butterfat production per lactation caused by delayed calving. For example, the total butterfat production to 7 years of age was 1,930 pounds for cows calving at 22 to 23 months, 1,910 pounds for cows calving at 24 to 25 months, and 1,810 pounds for cows calving at 26 to 27 months, the total quantity decreasing regularly until for cows calving at 34 to 35 months the total butterfat production to 7 years of age amounted to only 1,640 pounds.

TABLE 6.—*Relation of age at first calving to butterfat production for the first five lactations and to 7 years of age, and to the estimated mature live weight of the cows*[1]

Item	Age at first calving								
	18–21 months	22–23 months	24–25 months	26–27 months	28–29 months	30–31 months	32–33 months	34–35 months	36–42 months
Cows .... number	10	14	56	58	36	15	24	23	17
Average age at first calving ... months	19.3	22.6	24.4	26.4	28.6	30.3	32.6	34.5	38.2
Butterfat production, first lactation .... pounds	266	335	330	311	327	355	373	333	372
Total butterfat production, first five lactations ... pounds	1,868	1,963	1,912	1,875	1,900	1,966	2,000	2,048	2,016
Average age at end of 5 lactations .... months	84	86	84	87	89	92	96	98	103
Time from first calving to end of fifth lactation ... months	65	63	60	61	60	61	64	64	65
Butterfat production per month[2] .... pounds	29	31	32	31	32	32	31	32	31
Butterfat production to 84 months of age ... pounds	1,870	1,930	1,910	1,810	1,760	1,720	1,580	1,640	1,490
Estimated mature live weight .... pounds	1,250	1,260	1,250	1,260	1,240	1,220	1,310	1,300	1,350

[1] Data by Chapman and Dickerson (*199*) for 253 Holstein cows in 40 Wisconsin herds.
[2] Includes dry periods.

Another factor to be considered is the cost of raising the heifer to a producing age. As the age at first calving increases, the cost of raising heifers to a producing age also increases. The feeding of scanty rations may be false economy, as it retards the growth of the heifer and increases the age at which she should calve for the first time, and she may require as much total feed to producing age as a well-fed heifer. This is demonstrated by the data of Reed, Fitch, and Cave (*953*). Holstein heifers raised on skim milk and alfalfa hay without any grain were considerably below normal in size for age. They calved at an average age of 31.2 months with a live weight after calving of 767 pounds, consuming 420.3 pounds of whole milk, 2,360.7 of skim milk, and 12,918.2 of alfalfa hay, with a total feed cost of $86.39. Holstein heifers raised on skim milk, alfalfa hay, corn silage, and grain were about normal in size for age. Calving at an average age of 25 months with a live weight after calving of 983 pounds, they consumed 351.7 pounds of whole milk, 2,449.7 of skim milk, 5,480.1 of alfalfa hay, 7,265 of corn silage, and 1,947.1 of grain, with a total feed cost of $88.51. Calving at an average age of 28.4 months with a live weight after calving of 1,055 pounds, they consumed 354 pounds of whole milk, 2,388 of skim milk, 8,085.7 of alfalfa hay, 6,423.7 of corn silage, and 2,184.8 of grain, with a total feed cost of $102.23.

Considered from all angles, the feeding of dairy heifers so that they will grow at a rate about equal to that indicated by the Ragsdale and Fohrman-Swett growth standards (table 7, p. 625) will usually be the most satisfactory as well as the most economical practice. Such heifers will be sufficiently large and mature so that they can be bred at 15 to 18 months of age to calve when 24 to 27 months old. If properly managed and liberally fed after calving, heifers calving at this age will continue to grow at a nearly normal rate, and barring accident or disease, will produce the largest quantity of milk and butterfat up to a mature age and over an entire lifetime.

RAISING THE BULL CALF

The bull calf is slightly larger at birth than the heifer calf and will have a considerably larger size at maturity. He soon starts to grow at a more rapid rate than the heifer, and if given all the feed he requires, will be noticeably larger at 6 months of age. For Holsteins, this difference in size on good feeding may amount to over 100 pounds at 1 year of age, to 300 at 18 months, and to 350 pounds at 2 years; and for Jerseys, to 80 pounds at 1 year, to 140 at 18 months, and to 230 pounds at 2 years (tables 7 and 8, pp. 625 and 626).

The young bull calf should have about the same kind of feed and care as the young heifer calf. The two can be raised together at first, but after about 4 months of age bull calves should be kept in separate pens and lots. Because of the bull calf's more rapid growth rate and larger feed requirements he will need somewhat larger quantities of feed after he has reached 6 months of age.

The bull calf should have liberal quantities of good legume or mixed grass and legume hay, and all the grain he will eat up to 4 to 6 pounds daily to 6 months of age. With good hay fed in fairly liberal quantities the amount of grain required to keep a bull growing satisfactorily from 6 months of age on will rarely exceed 4 to 5 pounds daily. If a limited quantity of hay is fed or the hay is of poor quality, more grain may be required. The grain mixture should contain sufficient protein to supplement the roughage properly. Suitable grain mixtures are listed in table 4 (p. 614). Oats and linseed meal are particularly desirable ingredients to include in grain mixtures for dairy bulls. Silage is a bulky feed and has a tendency to distend the paunch, but it may be fed beginning at 3 or 4 months of age if limited to quantities not exceeding 1 pound a day for each month of age, or a total of not over 8 to 10 pounds daily for bulls 1 year old and

10 to 15 pounds daily for bulls 1 to 2 years of age or over. Moderate quantities of roots or other succulents or green forage crops in season may also be fed. A good-sized lot or small pasture that provides some green grass and considerable exercise is also desirable for growing bulls.

If in good growth and well developed, the dairy bull will be old enough for light service when 12 months old. His feeding from this time on should be such that he will be neither too fat nor too thin and will make about normal growth. The roughage fed should be limited to quantities that will not develop too much middle so that the bull will remain active and vigorous. More detailed information on the feeding and handling of dairy bulls will be found in Farmers' Bulletin 1412, Care and Management of Dairy Bulls (*270*).

NUTRITIONAL REQUIREMENTS

RATES OF GROWTH

Data on the size of well-fed dairy heifers at various ages and at maturity and on the rate of growth from birth to maturity, as measured by body weight and by height at withers, have recently been compiled by Ragsdale (*941*)[9] and by Fohrman and Swett.[10] These data are presented in table 7. The data of Ragsdale include heifers of the Ayrshire, Guernsey, Holstein, and Jersey breeds. Those of Fohrman and Swett include Holstein and Jersey heifers. The rate of growth and mature size of individual animals varies somewhat within each group shown. The Bureau of Dairy Industry Holstein and Jersey heifers grew at a little faster rate and were slightly larger at maturity than the Missouri, Iowa, and Kansas Holstein and Jersey heifers.

Body weight and height at withers increase most rapidly from birth to 6 or 9 months of age, then gradually slow down until the animal reaches maturity. Live weight increases very slowly after 6 years of age, with maximum weight at about 7 years. Height at withers increases very slowly after 4 or 5 years of age, with maximum height at 5 to 6 years. The live weight of the heifers at 2 years of age was 902 pounds for Ayrshires, 818 for Guernseys, 1,069 and 1,103, respectively, for Ragsdale and Fohrman-Swett Holsteins, and 733 and 805, respectively, for Ragsdale and Fohrman-Swett Jerseys. At 2 years of age, the heifers averaged 75.7 to 80.4 percent of their mature weight and 94.8 to 96.8 percent of their mature height.

Data on the body weight and height at withers of dairy bulls of the Ayrshire, Guernsey, Holstein, and Jersey breeds, compiled by Ragsdale (*941*), are presented in table 8. Because of the small number of animals of older ages on which data are available, these data are limited in the table to 9 months of age for Ayrshires, 12 for Guernseys, and 24 for Holsteins and Jerseys. Bulls are larger at birth and grow more rapidly than heifers.

Tables 7 and 8 may be taken to indicate the normal age weight of these breeds of dairy cattle and may be used to determine whether or not the young stock in a herd are growing at a satisfactory rate. The data of Moseley, Stuart, and Graves (*823*) on the effect of pregnancy on the live weight of Holstein cows, and that of Espe, Cannon, and Hanson (*335*) for Holstein, Jersey, Guernsey, and Ayrshire cows, indicate that at calving time the weight of the calf, placenta, and amniotic fluid will range from less than 100 pounds to more than 150 pounds depending on the breed. Four to six weeks after calving the cow may weigh 25 to 50 pounds less than immediately after calving owing to a rapid loss of flesh while milking heavily and failure to consume enough feed to meet total nutrient requirements.

There is a close relationship between the weight of dairy cattle and the distance around the chest just back of the forelegs. When it is not practical to weigh the animals, their weight can be estimated closely by measuring at this point. Tables giving chest measurements in inches and the corresponding live weight of the animal have been compiled by Kendrick and Parker[11] from Bureau of Dairy Industry data, by Ragsdale and Brody (*943*) from Missouri data, and by Davis and Morgan (*269*) from Nebraska data.

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[9] Includes growing dairy cattle located in the dairy herds of the Missouri, Iowa, and Kansas Agricultural Experiment Stations.

[10] Unpublished data, collected from 1920 to 1938, on the growth of dairy cattle in the breeding herd of the Bureau of Dairy Industry, Agricultural Research Center, Beltsville, Md.

TABLE 7.—*Live weight and height at withers of well-fed dairy heifers at different ages from birth to 7 years*

Age (months)	Ragsdale[1]								Fohrman and Swett[2]			
	Ayrshire		Guernsey		Holstein		Jersey		Holstein		Jersey	
	Live weight	Height at withers	Live weight	Height at withers	Live weight	Height at withers	Live weight	Height at withers	Live weight	Height at withers	Live weight	Height at withers
	Lb.	*In.*	*Lb.*	*In.*	*Lb.*	*In.*	*Lb.*	*In.*	*Lb.*	*In.*	*Lb.*	*In*
Birth	72	27.6	65	26.6	90	29.1	53	25.7	94		55	-
1	89	28.6	77	28.2	112	30.6	67	27.0	118		72	-
2	119	30.2	102	29.8	148	32.3	90	28.9	157	-	102	
3	158	31.9	133	31.6	193	34.3	121	30.6	204	34.6	137	31.9
4	198	34.0	173	33.5	243	36.2	158	32.6	257		178	
5	245	35.5	216	35.3	297	37.7	199	34.5	317		226	-
6	293	37.2	260	36.9	355	39.7	243	36.2	375	40.0	273	37.5
9	433	40.9	389	40.9	509	43.5	360	40.1	535	43.8	404	41.2
12	538	43.2	490	43.3	632	46.0	450	42.2	685	46.4	512	43.2
15	638	45.1	584	45.0	746	47.9	535	43.9	785	-	579	
18	725	46.5	663	46.4	845	49.3	601	45.2	889	49.7	654	46.0
21	818	47.6	737	47.3	952	50.6	665	46.2	1,002	--	729	-
24	902	48.3	818	48.0	1,069	51.7	733	46.9	1,103	---	805	-
27	909	48.1	876	48.9	1,151	52.2	816	47.7	1,146	-	847	
30	945	48.3	880	49.3	1,120	52.5	824	47.9	1,167	[3] 52.7	872	[4] 48.5
33	965	48.9	905	49.7	1,130	52.7	832	48.0	1,209	--	898	--
36	968	48.7	901	49.9	1,165	53.0	855	48.2	1,265		927	--
39	1,007	49.1	924	50.0	1,176	53.1	899	48.6	1,296	-	950	--
42	1,014	49.9	952	49.9	1,202	53.2	895	48.6	1,292	----	955	- -
45	1,038	50.0	971	50.1	1,197	53.2	898	48.5	1,294	[5] 53.6	954	[6] 49.1
48	1,035	50.2	990	50.4	1,232	53.3	897	48.5	1,329	- -	959	---
54	1,058	50.3	1,024	50.5	1,271	53.6	952	48.6	1,343		990	- --
60	1,080	50.4	1,055	50.6	1,330	53.6	937	49.0	1,367		994	---
66	1,055	49.2	1,051	50.0	1,312	53.7	955	48.7	1,383	----	1,007	--
72	1,132	49.1	1,093	49.7	1,317	53.7	973	48.4	1,400	[7] 54.2	1,034	[8] 49.1
78	1,080	48.9	1,084	49.4	1,357	54.0	998	48.6	1,436	-	1,059	--
84	1,122	48.7	1,066	49.3	1,401	53.7	959	48.0	1,424		1,064	---
Average daily gains in live weight to 2 years:												
Birth to 6 months	1.21	------	1.07	--	1.45	--	1.04	- -	1.53	---	1.19	- --
6 to 12 months	1.34	-- --	1.26	--	1.52	-----	1.13	- ---	1.70	- ---	1.31	---
12 to 18 months	1.02	------	.95	-----	1.17		.83	----	1.12	------	.78	-- -
18 to 24 months	.97	------	.85	----	1.23	------	.72	---	1.17	------	.83	-
Birth to 24 months	1.14	--	1.03		1.34	---	.93		1.38	-----	1.03	----

[1] Includes animals in the herds of the Missouri, Iowa, and Kansas Agricultural Experiment Stations (*941*). Ayrshire weight data include 100 head or more to 16 months, 87 at 24 months, 29 at 5 years, and 16 at 7 years; Holsteins, 200 head or more to 12 months, 140 at 2 years, 41 at 5 years, 27 at 7 years; Jerseys, 150 or more to 12 months, 118 at 2 years, 36 at 5 years, and 25 at 7 years. The number of animals included in height at withers data is only slightly smaller.

[2] Unpublished data on the growth of dairy cattle in the herd of the Bureau of Dairy Industry, Research Center for Agriculture, Beltsville, Md. The data on live weight were collected by M. H. Fohrman from 1920 to 1938. Holstein data include over 200 head to 15 months, 182 at 2 years, 107 at 5 years, and 64 at 7 years. Jersey data include 200 head or more to 2 years, 130 at 5 years, and 87 at 7 years. The data on height at withers were collected by W. W. Swett and C. A. Matthews from 1924 to 1938. The measurements beyond 18 months were taken at approximately 3 to 4 months after first calving, second calving, and a calving at approximately mature age. Holstein data include 130 to 184 animals to 18 months, and 136, 82, and 50 animals, respectively, 3 to 4 months after first calving,[3] second calving,[5] and a mature-age calving.[7] Jersey data include 135 to 222 animals to 18 months, and 160, 86, and 68 animals, respectively, 3 to 4 months after first calving,[4] second calving,[6] and a mature-age calving.[8]

[3] Average ages 2 years 5 months 26 days.
[4] 2 years 6 months 2 days.
[5] 3 years 8 months 13 days.
[6] 3 years 9 months 20 days.
[7] 6 years 1 month 17 days.
[8] 6 years 1 month 12 days.

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[11] KENDRICK, J. F., and PARKER, J. B. ESTIMATING THE WEIGHT OF DAIRY COWS FROM HEART GIRTH MEASUREMENTS. U. S. Bur. Dairy Indus. B. D. I. M. No. 695, 2 pp. 1936. [Mimeographed.]

Table 8.—*Live weight and height at withers of well-fed dairy bulls at different ages from birth to 2 years* [1]

Age (months)	Ayrshire		Guernsey		Holstein		Jersey	
	Weight	Height	Weight	Height	Weight	Height	Weight	Height
	Pounds	*Inches*	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*	*Inches*
Birth	81	27.9	71	27.7	94	29.4	60	26.2
1	101	29.4	87	29.3	125	31.2	78	27.9
2	133	30.9	113	30.6	164	33.2	104	29.7
3	173	32.7	147	32.4	214	34.8	141	31.5
4	217	34.5	190	34.2	269	36.4	184	33.6
5	267	36.1	237	36.1	336	38.8	233	35.5
6	321	37.9	291	37.8	399	40.5	282	37.2
9	488	41.8	443	41.5	563	44.2	410	40.4
12	--------	--------	609	44.5	741	47.5	531	43.0
15	--------	--------	--------	--------	978	49.7	643	45.5
18	--------	--------	--------	--------	1,176	52.2	745	47.5
21	--------	--------	--------	--------	1,345	54.3	875	48.0
24	--------	--------	--------	--------	1,438	55.9	969	50.3

[1] Compiled by Ragsdale (*941*). Includes animals in the herds of the Missouri, Iowa, and Kansas State Agricultural Experiment Stations. The number of animals included for Ayrshires were 92 at birth and 31 at 9 months; for Guernseys, 50 at birth and 15 at 9 months; for Holsteins, 159 at birth, 120 at 6 months, 35 at 12 months, and 2 at 24 months; Jerseys, 100 at birth, 82 at 6 months, 23 at 12 months and 3 at 24 months.

FEED REQUIREMENTS FOR GROWTH

The feed constituents on which young dairy cattle grow are proteins, carbohydrates (including sugars, starches, and crude fiber), fats, minerals, and vitamins. Collectively, the digestible part of these constituents in feeds (including digestible fat multiplied by 2.25) is termed "total digestible nutrients." Water contains no feed nutrients, but it also is vital to life and growth. Many experiments have been conducted to determine the nutritional requirements of growing dairy animals for the various constituents, and a number of feeding standards have been proposed.

The first feeding standards for growing dairy cattle used in this country originated in Europe. The Wolff-Lehmann standard, published by Henry (*506*), proposed quantities of digestible crude protein and total digestible nutrients per day per 1,000 pounds live weight, for maintenance and growth combined. Armsby (*32*) reviewed the work of many European investigators including that of Kellner and proposed a feeding standard that gave quantities of feed nutrients in terms of net energy and digestible crude protein per animal per day for maintenance alone and for maintenance and growth combined. Since then Morrison (*819*) has revised the Wolff-Lehmann feeding standard as a result of American experiments. This standard, now known as the Morrison feeding standard, proposes minimum and maximum quantities of digestible crude protein and total digestible nutrients (also net energy) to feed per animal per day for maintenance and growth combined. Gullickson and Eckles (*297*, *449*) conducted feeding trials with Holstein and Jersey heifers and have proposed total digestible nutrient requirements per animal per day for maintenance and for growth. Mitchell (*795*) has reviewed many American protein experiments and proposed minimum protein requirements for maintenance and for maintenance and growth. Brody, Procter, and Ashworth (*157*) have calculated from the energy metabolism of fasting animals and from the protein metabolism of animals on a protein-free or very low protein diet, the total digestible nutrient and digestible crude protein requirements for the maintenance of all kinds and sizes of animals, including growing dairy cattle.

Total Digestible Nutrient Requirements

In feeding growing dairy cattle, it is necessary to provide plenty of total digestible nutrients or total energy for maintenance and normal growth. Energy is used up in the processes of digestion and metabolism, in maintaining the temperature of the body at blood heat, and in breathing and exercising. Energy is also stored in the gains in live weight made by the growing animal in the form of protein and fat. The quantity of total digestible nutrients required for maintenance and normal growth may vary considerably.

Table 9 gives the quantities of total digestible nutrients required for maintenance and growth combined, as proposed by Morrison (*819*), and requirements for maintenance, for 1 pound of gain, and for maintenance and growth combined, based on the experiments of Gullickson and Eckles with Holstein and Jersey heifers. In calculating the Gullickson-Eckles requirements, the figures used for maintenance are those given by Gullickson and Eckles (*449*); the requirements per pound of gain were obtained by applying a straight-line formula after the method of Mills (*792*) to the original data of Eckles and Gullickson (*297*) for digestible nutrients, above the maintenance requirement, consumed per pound of gain by Holstein and Jersey heifers making about normal growth; and the total requirements for maintenance and growth are based on growth at a rate equivalent to an average of that shown by Ragsdale and by Fohrman and Swett in table 7 for Holstein and Jersey heifers.

TABLE 9.—*Total digestible nutrients per head daily required for growth of dairy cattle, calculated from the Gullickson-Eckles data, and compared with the Morrison feeding standard*

Live weight of animal (pounds)	Normal daily gains in live weight[1]		Total digestible nutrients per head daily						
			Gullickson-Eckles					Morrison[5]	
			For maintenance[2]	For 1 pound of gain[3]		For maintenance and growth[4]		For maintenance and growth	
	Holstein heifers	Jersey heifers		Holstein heifers	Jersey heifers	Holstein heifers	Jersey heifers	Minimum	Maximum
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
75		0.60					1.53		
100	0.80	1.00	0.78	1.08	1.585	1.64	2.36	1.2	2.0
150	1.40	1.30	1.50	1.13	1.618	3.08	3.60	2.3	3.0
200	1.65	1.40	2.17	1.18	1.634	4.12	4.54	3.3	4.0
250	1.80	1.55	2.81	1.23	1.651	5.02	5.37	4.1	4.8
300	1.90	1.40	3.41	1.28	1.667	5.84	5.74	4.9	5.5
350	1.90	1.30	3.98	1.33	1.683	6.51	6.17	5.5	6.1
400	1.85	1.20	4.50	1.38	1.700	7.05	6.54	6.1	6.6
450	1.75	1.10	5.00	1.43	1.716	7.50	6.89	6.5	7.2
500	1.65	1.00	5.45	1.48	1.733	7.89	7.18	6.9	7.7
550	1.55	.90	5.87	1.53	1.749	8.24	7.44	7.3	8.2
600	1.40	.80	6.24	1.58	1.765	8.45	7.65	7.7	8.7
650	1.30	.80	6.59	1.63	1.782	8.71	8.01	8.1	9.2
700	1.25	.90	6.89	1.68	1.798	8.99	8.51	8.4	9.7
750	1.20	1.00	7.16	1.73	1.814	9.24	8.97	8.8	10.2
800	1.20	1.10	7.39	1.78	1.831	9.53	9.40	9.1	10.7
850	1.20		7.59	1.83	1.847	9.79		9.5	11.2
900	1.25		7.74	1.88	1.863	10.09		9.8	11.7
950	1.30		7.87	1.93	1.880	10.38		10.1	12.2
1,000	1.35		7.95	1.98	1.896	10.62		10.4	12.6

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[1] Calculated from Ragsdale and Fohrman-Swett data given in table 7.

[2] As calculated by Gullickson and Eckles (*449*) applying method of least squares to data.

[3] Calculated from the original data of Eckles and Gullickson (*297*) using the straight-line formula of Mills (*792*).

[4] Gullickson-Eckles maintenance and growth requirements applied to Ragsdale and Fohrman-Swett daily gains in live weight.

[5] Intermediate figures added to Morrison's table at 350, 450, 550, 650, 750, 850, and 950 pounds live weight.

The Gullickson-Eckles maintenance requirement of 7.95 pounds total digestible nutrients at 1,000 pounds live weight coincides with that of Haecker for dairy cows, which is used by Savage and by Morrison. For animals under 1,000 pounds live weight, the maintenance requirement up to 300 pounds is less, and over 300 pounds is greater than an amount calculated on the two-thirds power of the live weight.

The quantity of total digestible nutrients required for 1 pound of gain is higher for Jerseys than for Holsteins of the same live weight. On the other hand, the Holsteins made larger average daily gains than the Jerseys, and the total requirements for maintenance and growth combined are approximately the same for Holsteins and Jerseys of the same live weight.

The total requirements for maintenance and growth combined equal or exceed the Morrison maximum requirements up to a live weight of 500 pounds for Holsteins and 350 pounds for Jerseys, after which they gradually approach the Morrison minimum requirements, until at 800 pounds live weight for Jerseys and 1,000 pounds for Holsteins they are only slightly above the Morrison minimum.

In controlled feeding experiments involving a limited number of animals, Converse [12] raised Holstein and Jersey heifers (five of each breed) from birth to 2 years of age, with growth at a normal rate, on a ration that provided nutrients at about the rate shown by the Gullickson-Eckles data, but with slightly less nutrients after the heifers were 1 year old than these data called for. These heifers were fed whole milk to 1 month, and skim milk in moderate quantities to 6 months, together with moderate quantities of grain and liberal quantities of good roughage. The heifers made as good growth for age as heifers of the same breed reported by Ragsdale (*942*), which were fed somewhat more total digestible nutrients after 16 months of age in a ration that consisted of whole milk to 1 month and liberal quantities of skim milk to 6 or 8 months, together with liberal quantities of grain and limited quantities of roughage.

Protein Requirements

Supplying plenty of protein according to the growing animal's needs is as important as supplying plenty of energy. The proteins are complex nitrogenous compounds made up of simpler substances known as amino acids. Of the 22 known amino acids only 10 have been found to be essential for normal growth with the rat. No experiments of this sort have been conducted with larger animals.

Most of the gain in live weight made by growing dairy animals consists of lean or muscular tissue high in protein content. The protein content of the gains made by normally growing dairy animals is no doubt quite similar to that found by Moulton, Trowbridge, and Haigh (*826*) for growing young stock. They found that the protein content of the gains made by steers fed enough nutrients for nearly normal growth with little or no fattening was about 22 percent for a calf weighing 100 pounds, decreasing gradually to about 14 percent for an animal weighing about 1,000 pounds. Because of the changes in both the rate of gain in live weight and the percentage of protein in the gains made, the quantity of protein required for growth increases rapidly from birth until the animal is making the greatest gains, declines slowly during the period of greatest gains, and then declines more rapidly as the rate of gain declines.

In addition to that stored in the lean tissues of the growing animal's body, protein is used up or lost in the processes of digestion and metabolism required to maintain the body. Instead of being stored, this protein is broken down (katabolized) and excreted as waste products, principally in the urine. The quantity of protein required for maintenance is small at first because of the small size of the animal. As the size of the animal increases, the total quantity of protein required for maintenance also increases, the increase being proportional to the increase in size.

The amount of protein required for normal growth by young dairy stock of the same age and size may vary widely depending upon the nature of the ration and the quantity fed. A minimum quantity of protein will be required if the ration provides an ample supply both of energy and of protein that contains all the essential amino acids. On the other hand, considerably more protein may be required if that supplied is low in one or more of the essential amino acids. If the amount of energy supplied for growth is inadequate, more protein will also be required, since part of the protein will be used up as a source of energy and will not be available for body building and repair. If the ration contains a considerable excess of protein it will not be efficiently utilized, but this may be compensated for by a more than normal rate of growth, provided the ration also contains plenty of energy.

Protein of the highest quality and digestibility for the young calf is provided by milk and milk products. Hay proteins are usually relatively low in one or more of the essential amino acids. Farm grains usually contain the essential amino acids that may be lacking in hay, and these two classes of feeds combined furnish protein of good quality for growing young stock. Where high-protein concentrates are used to balance the ration, they increase the variety of amino acids and tend to insure a protein mixture of higher quality for the growing animal.

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[12] From unpublished reports of experiments by H. T. Converse on the feed requirements for growth in dairy cattle. The feed consumed, live weight at different ages, and gains made are reported in Farmers' Bulletin 1723, Feeding, Care, and Management of Young Dairy Stock (*1037*).

There is little experimental data on the protein requirements of dairy calves under 6 months of age. However, feeding trials to determine the minimum protein requirements of growing dairy cattle 6 to 24 months old have been conducted by Swett, Eckles, and Ragsdale (*1116*) at the Missouri station, and cooperative protein experiments sponsored by the National Research Council have been conducted at a number of other stations. Armsby (*32*) has reported on the cooperative protein experiments conducted in Massachusetts, Ohio, and Virginia. Forbes, Bechdel, Jeffries, and Kriss (*370*) have reported on the cooperative experiments conducted in Pennsylvania, North Dakota, South Dakota, Maryland, and Nebraska. These experiments did not indicate a satisfactory minimum protein requirement for normal growth. They did show that if the ration fed provided an abundance of energy, growing animals could make normal or nearly normal growth on considerably less protein than either the Armsby (*32*) or the Wolff-Lehmann (*506*) standards called for.

In the experiment conducted by Swett, Eckles, and Ragsdale, Holstein, and Jersey heifers 6 to 24 months old that were fed total nutrients equal to 130 percent of the Armsby energy standard made normal growth with about 70 percent and more than normal growth with about 80 percent of the Wolff-Lehmann protein requirements. Other Holstein and Jersey heifers that were fed total nutrients equal to only 103 to 107 percent of the Armsby energy standard made less than normal growth with about 110 percent of the Wolff-Lehmann protein requirements.

On the basis of these findings by American experiment stations, Morrison (*819*) has proposed a range in the quantities of protein allowed in which the minimum protein allowance for maintenance and growth combined averages about 80 percent, and the maximum averages about 90 percent, of the original Wolff-Lehmann standard.

Mitchell (*795*) has also reviewed these experiments and has suggested tentative minimum protein requirements in line with the results shown for certain animals receiving the lowest protein intake. His tentative protein requirements are considerably lower than the minimum figures of Morrison, the total quantity of protein for maintenance and growth combined decreasing with the age of the animal. In calculating protein requirements for growth, Mitchell allowed twice as much digestible protein per pound gain as the data of Moulton, Trowbridge, and Haigh (*826*) indicated was stored in each pound of gain made by young steers growing normally with very little fattening. In calculating maintenance requirements, Mitchell (*1086*) considered that an allowance of digestible crude protein equivalent to twice the quantity of urinary nitrogen excreted on a protein-free diet (endogenous urinary nitrogen), varied as the 0.734 power of the live weight of the animal, would be ample. He regards fecal nitrogen as derived entirely from the "indigestible" protein fraction of the feed and uses a biological value of 50 percent for the digestible protein fraction used in maintenance and growth.

The method used by Mitchell for calculating protein for maintenance allows only 0.35 pound of digestible crude protein as compared with the allowance for maintenance of 0.60 pound of protein by Armsby (*33*) and by Forbes and Kriss (*374*), 0.60 to 0.65 pound by Morrison (*819*), and 0.70 pound by Haecker (*454*) and by Brody, Procter, and Ashworth (*157*). Brody has calculated his maintenance requirements on the basis of endogenous urinary nitrogen, varied as the 0.72 power of the live weight of the animal, but has allowed digestible crude protein equivalent to four times the quantity of urinary nitrogen excreted on a protein-free diet, or double the allowance of Mitchell. The methods used by Mitchell in arriving at the protein requirements for maintenance are open to some criticism because (1) the endogenous nitrogen metabolism of the cow cannot actually be determined since any ration that can be fed under present conditions of knowledge will always contain some nitrogen, and (2) not all experimenters agree in finding that 2 milligrams of endogenous nitrogen is equivalent to 1 calorie of basal heat metabolism.

In table 10 the protein requirements of Holstein and Jersey heifers making normal growth have been calculated according to the method of Mitchell, and also on the basis of Brody's maintenance and Mitchell's growth requirements, and protein allowances by these two standards are compared with the protein allowances of the Armsby and Morrison standards. The Armsby standard allows as much protein for maintenance and growth as the Morrison maximum up to about 500 pounds live weight, after which it corresponds closely to the Morrison minimum. Mitchell's standard allows more protein than the Morrison maximum calls for up to about 400 pounds live weight for Holsteins and 200 pounds live weight for Jerseys, after which it drops below the Morrison minimum. The Brody-Mitchell standard allows more protein for Holsteins up to about 500 pounds live weight than either the Armsby or Morrison maximum calls for, and then corresponds closely to the Armsby and to the Morrison minimum requirements. For Jerseys, the Brody-Mitchell standard is slightly above the Armsby and the Morrison maximum standards up to 300 pounds live weight and is then slightly below these standards.

TABLE 10.—*Digestible crude protein per head daily for growing dairy cattle, calculated to a normal growth rate for the Mitchell and Brody-Mitchell feeding standard, and compared with the Armsby and Morrison feeding standards*

Live weight of animal (pounds)	Normal daily[1] gains in live weight		Digestible crude protein per head daily										
			Mitchell[2]				Brody-Mitchell[3]			Armsby[4]		Morrison[5]	
			For maintenance	For 1 pound gain	For maintenance and growth		For maintenance	For maintenance and growth		For maintenance	For maintenance and growth	For maintenance and growth	
	Holstein heifers	Jersey heifers			Holstein heifers	Jersey heifers		Holstein heifers	Jersey heifers			Minimum	Maximum
	Lb.	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb*	*Lb.*
100	0.80	1 00	0.06	0.43	0.40	0.49	0.13	0.47	0.56	0.06	0.48	0.24	0.40
150	1.40	1.30	.09	.43	.69	.65	.18	.78	.64	.09	.60	.41	.52
200	1.65	1.40	.11	.42	.80	.70	.22	.91	.81	.12	.72	.52	.62
250	1.80	1.55	.13	.42	.89	.78	.25	1.01	.90	.15	.80	.61	.71
300	1.90	1.40	.14	.41	.92	.71	.29	1.07	.88	.18	.87	.67	.78
350	1.90	1.30	.16	.40	.92	.68	.33	1.09	.85	.21	.92	.73	.84
400	1.85	1.20	.18	.39	.90	.65	.36	1.08	.83	.24	.96	.80	.90
500	1.65	1.00	.21	.37	.82	.58	.42	1.03	.79	.30	1.00	.87	.98
600	1.40	.80	.24	.36	.74	.53	.48	.98	.77	.36	1.02	.94	1.06
700	1.25	.90	.27	.34	.70	.58	.54	.97	.85	.42	1.02	1.00	1.13
800	1.20	1.10	.29	.32	.67	.64	.59	.97	.94	.48	1.02	1.06	1.20
900	1.25	-----	.32	.30	.70	-----	.65	1.03	----	.54	-----	1.11	1.27
1,000	1.35	-----	.35	.28	.73	-----	.70	1.08	----	.60	-----	1.16	1.33

[1] Calculated from Ragsdale and Fohrman-Swett data in table 7.

[2] Digestible crude protein requirements for maintenance calculated according to Mitchell (Smuts, *1086*), using the following equations: (1) The basal heat metabolism in calories $= Q = 70.4m^{.734}$ in which m is the body weight in kilograms. (2) 1 calorie of basal metabolism corresponds to 2 milligrams of endogenous nitrogen metabolism or 12.5 milligrams of endogenous protein metabolism. (3) Grams of protein lost daily in endogenous protein metabolism $= P = 0.88\ m^{.734}$. (4) And if the feed protein used to cover this loss has a biological value of 50, the digestible feed protein required for maintenance $= 1.76\ m^{.734}$. Digestible crude protein for gain in body weight calculated by Mitchell as twice the protein contained in the gain. Body gains used here are those reported by Moulton, Trowbridge, and Haigh (*826*) for steers growing at about a normal rate with little or no fattening.

[3] The digestible crude protein for maintenance is calculated by Brody, Procter, and Ashworth (*157*) as 4 times that equivalent to the endogenous nitrogen loss. The endogenous nitrogen loss (N) in milligrams, according to Brody, is equivalent to $146\ m^{.72}$, where m is the weight of the animal in kilograms. The digestible crude protein required for gains in body weight calculated by method of Mitchell (see footnote 2).

[4] Armsby's original requirements (*33*) transposed from digestible true protein to digestible crude protein by adding 20 percent to his figures for true protein, a method advocated by Armsby himself. Where Armsby's requirements were not given for live weights shown in the table, the intermediate data were calculated as proportional to live weight.

[5] As given by Morrison (*819*) except that at 350 pounds live weight the averages of the data for 300 and 400 pounds live weight are used.

Mitchell's protein allowance for growth seems ample but his allowance for maintenance inadequate. When the calf is small, protein is used principally for growth. As the calf gets older more protein is required for maintenance and less is used for growth, and the total quantity of protein allowed by the Mitchell standard approaches closer and closer to what might be considered a minimum under ideal feeding conditions.

In actual feeding practice, it is wise, as a factor of safety, to provide more protein in the ration than the minimum requirement and thus prevent an actual shortage of protein in case there is some shortage of total digestible nutrients or the ration fed is low in one of the essential amino acids. For this reason, it would seem best to feed more protein to growing dairy cattle than is called for by the Armsby or the Morrison minimum standard. If above-normal growth is desired, it is well to feed liberally and allow as much protein as is called for by the Morrison maximum. Where legume hays are fed, it is possible to provide plenty of protein with little cash outlay for purchased feeds, and many rations commonly fed to growing dairy cattle contain a considerable excess of protein.

Minerals

Mitchell and McClure (*803*) state that calcium, phosphorus, sodium, potassium, chlorine, magnesium, iron, sulfur, iodine, manganese, copper, zinc, and possibly cobalt have been demonstrated as performing essential functions in the animal body and are therefore necessary in the feed. Very few of these elements have been shown to be deficient in the normal ration of growing calves.

Salt

Of the necessary mineral elements, sodium and chlorine, found in common salt, are the only ones always needed as a supplement to normal calf rations. Salt may be included as 0.5 to 1.0 percent of the grain mixture and may also be kept in a box available to the calves at all times.

Calcium and Phosphorus

Calcium and phosphorus have been reported as deficient in calf rations. The actual amounts of these elements necessary for the well-being and maximal growth of dairy calves do not seem to be definitely known. The minimum quantities suggested by three State agricultural experiment stations are considerably different. As summarized by Mitchell and McClure (*803*) they range from 0.18 percent (or less) to 0.43 percent of the dry matter in the ration for calcium and from 0.10 to 0.26 percent of the dry matter for phosphorus. The Massachusetts Agricultural Experiment Station, feeding mixed grass hay (0.40- to 0.54-percent calcium) with a very little alfalfa hay during the first year as a low-calcium roughage, reported somewhat lower calcium retention, as shown by balance experiments, than when alfalfa hay was fed; and the West Virginia station, feeding timothy hay (0.38-percent calcium) as roughage, reported somewhat lower gains at 2 years of age than when alfalfa hay was fed. On the other hand, the Michigan station, feeding somewhat smaller amounts of calcium than those reported above, reports just as good gains from 6 months of age to first calving with the timothy hay ration as with the alfalfa hay ration.

The Bureau of Dairy Industry (*1156*), using low-calcium timothy hay (0.20- to 0.35-percent calcium), reported no advantage in adding bonemeal as a calcium supplement. The 12-month experimental period started at 6 months of age and ended at 18 months. The Missouri Agricultural Experiment Station (*300*) does appear to have demonstrated calcium deficiency in one Jersey heifer getting corn silage, corn stover, timothy hay, corn, and corn gluten feed. The heifer grew as well from 7 to 17 months of age as did a similar heifer getting alfalfa hay, but at 18 months rachitic symptoms developed, which were cured by adding bonemeal. The calcium intake was very low—about 5.5 grams a day, or 2 grams per hundredweight, at 8 months and 5.95 grams a day, or 1 gram per hundredweight, at 17 months. These amounts are below the calcium requirements of Mitchell and McClure (*803*). A table of calcium and phosphorus requirements prepared by these authors is included here as table 11.

The results of the various experiments indicate that the customary calf rations that include grain and hay supply sufficient amounts of calcium and phosphorus for normal growth. These rations seem adequate for calcium even when low-calcium grass hay is the roughage fed, provided the amount of hay is not severely restricted.

There have been indications from several States of areas where the phosphorus of the forage is particularly low, especially in dry years, and in some States actual phosphorus deficiency has been demonstrated in the animals fed home-grown rations. Eckles, Gullickson, and Palmer (*298*) reported that phosphorus deficiency was more or less prevalent in 30 counties of Minnesota. In these sections when the animals were fed largely on home-grown feeds deficiency symptoms usually developed, but if considerable amounts of concentrates that had been shipped in were fed, the animals were frequently not affected. These investigators stated that unmistakable phosphorus-deficiency symptoms occur in certain

TABLE 11.—*Estimated calcium and phosphorus requirements of growing Holstein-Friesian cattle (female)* [1]

Body weight (pounds)	Dry-matter [2] requirement	Net requirement of calcium	Feed calcium required	Necessary percentage of calcium in ration	Net phosphorus requirement	Feed phosphorus required	Necessary percentage of phosphorus in ration
	Grams	*Grams*	*Grams*	*Percent*	*Grams*	*Grams*	*Percent*
300	3, 388	7. 9	11. 3	0. 33	7. 2	10. 3	0. 30
400	3, 889	7. 3	10. 4	. 27	7. 3	10. 4	. 27
500	4, 416	6. 6	9. 4	. 21	7. 3	10. 4	. 24
600	4, 784	6. 1	8. 7	. 18	7. 3	10. 4	. 22
700	5, 188	5. 4	7. 7	. 15	7. 2	10. 3	. 20
800	5, 518	5. 0	7. 1	. 13	7. 2	10. 3	. 19
900	5, 800	4. 5	6. 4	. 11	7. 2	10. 3	. 18
1,000	6, 196	4. 1	5. 9	. 10	7. 2	10. 3	. 17
1,100	6, 597	3. 9	5. 6	. 08	7. 4	10. 6	. 16
1,200	6, 947	3. 8	5. 4	. 08	7. 6	10. 9	. 16

[1] Table 10, p. 131, Mitchell and McClure, Mineral Nutrition of Farm Animals (*803*).

[2] In computing the dry-matter requirements, the ratios of dry matter to total digestible nutrients required are the same at different body weights as those recommended by the Morrison standards.

sections of Wisconsin, Colorado, Utah, Nevada, New Mexico, and Florida and that bone chewing on certain ranges in California indicated that there were phosphorus-deficient areas in that State. The early symptoms of the deficiency are bone chewing and the gnawing of wood. Symptoms reported as developing later are poor physical appearance, poor appetite, stiffness in the joints, and sometimes fragile bones that break easily. In the feeding experiments of Eckles, Gullickson, and Palmer phosphorus deficiency was demonstrated when the phosphorus intake was as high as 7 to 8 grams daily, not far below the minimum requirement shown in table 11.

A deficiency of phosphorus can easily be corrected. Wheat bran and linseed meal are rich in phosphorus. Bonemeal is rich in both calcium and phosphorus and may be fed if needed as 1 percent of the grain ration or kept where the calves have access to it. Only bonemeal intended for animal or poultry feeding should be used. Rock phosphate should not be fed because of its high content of fluorine, which seriously affects the bones and teeth of animals.

Iodine

In certain regions where goiter or "big neck" occurs, iodine may be deficient. These goitrous regions occur more frequently in the Northwestern and the Lake States than elsewhere in this country. Areas deficient in this element have been noted in California, Washington, Oregon, Idaho, Montana, Utah, Wyoming, North Dakota, Minnesota, and Ohio. If goiter does occur, additional iodine need be given only to pregnant cows and heifers so that the calf may be normal at birth. This iodine can be provided by mixing 1 tablespoonful of a 5-percent solution of potassium or sodium iodide daily in the feed of the pregnant animal; or iodized salt can be fed during the last half of the gestation period. Iodized salt should contain 0.02 percent of potassium or sodium iodide, which is equivalent to one-third of an ounce (9.45 grams) per 100 pounds of salt.

Iron and Copper

Malnutrition of cattle caused by a deficiency of iron and copper has been demonstrated in some isolated areas. The Florida Agricultural Experiment Station (*82*) found that "salt sickness" or nutritional anemia of cattle in certain sandy areas in that State was cured by the administration of iron (ferric ammonium citrate) and very small amounts of copper sulfate.

Cobalt

With the possible exception of cobalt, other mineral elements are probably present in sufficient amounts in the calf ration. Cobalt has been definitely shown to be essential in animal nutrition, and this element has been shown to cure certain deficiency diseases of sheep in New Zealand and Australia. In this country cobalt-deficient areas have been reported in Florida.

Vitamins

Calves may be born dead, weak, or blind (*217*) if their dams have been fed rations deficient in vitamin A. Calves that are normal at birth have very small reserve stores of vitamin A even when their dams have had satisfactory rations before calving. It is necessary therefore for the calf to receive feed containing vitamin A from birth. Colostrum has been shown (*1026*) to be several times as potent in carotene and vitamin A as milk produced some days after calving. The importance of vitamin A in the calf ration after the colostrum period is shown by a series of four experiments carried out at the Bureau station at Beltsville (*218*, *219*). These experiments also show the influence of the ration fed the lactating cow on the vitamin A content of the milk produced, as well as methods of furnishing the vitamin A required by the calf.

In the experiments at Beltsville, the calves were from cows that had been well fed on rations adequate in vitamin A. For 3 days after birth all of them received their mothers' colostrum. The milk-feeding regime, sources of the milk fed, vitamin A supplements used, and the grain and hay fed to the calves, as well as the results of these experiments, are shown in table 12. In experiments 1, 2,

TABLE 12.—*The effect of different milks and vitamin A supplements on the rate of growth of young calves allowed access to grain and poor-quality hay*

Experiment No.	Group	Number of calves[1]	Milk-feeding regime with calves[2]	Source of vitamin A in feed of cows producing the milk	Results[3]
1	I	7	Whole milk for 20 days with gradual change to skim milk at 30 days of age; skim milk to 6 months of age.	U. S. No. 3 timothy hay, late cut.	All died at from 45 to 89 days of age.
	II	5	do	U. S. No. 1 timothy or clover light timothy mixed hay.	4 calves died at from 76 to 95 days of age.[4] The fifth became blind at 4 months, but lived to end of experiment at 6 months of age.
	III	6	do	U. S. No. 1 alfalfa hay	4 died at 55 to 168 days of age. The 2 others survived experimental period, but growth was very subnormal.
	IV	4	do	Pasture	All survived the experimental period. Growth was 40 to 80 percent of normal.
2	I	2	Whole milk to 6 months of age.	U. S. No. 1 alfalfa hay	Growth 65[5] and 80 percent of normal.
	II	2	do	Pasture	Growth normal.
3	I	5	Skim milk to 6 months +10 or 20 ml. cod-liver oil daily.	Mixed barn rations (no pasture).[6]	Do.
	II[7]	4	Skim milk to 6 months +60 gm. carrots daily.	do	Growth 48 percent of normal; 1 blind, another blind in 1 eye.
	III[7]	4	Skim milk to 6 months +180 gm. carrots daily.	do	Growth 81 percent of normal.
[7] 4		3	Same as experiment No. 1.	U. S. No. 3 timothy hay, late cut.	1 died at 52 days of age.[8] The other 2 made normal gains in weight.

[1] All calves, except in experiment 4, had access to grain (see text) and U. S. No. 3 timothy hay. The calves in experiment 4 had access to grain and No. 1 alfalfa hay. The grain mixture consisted of wheat bran, ground yellow corn, linseed meal, and soybean meal.

[2] Comparable quantities of milk were fed to calves of the same breed in all experiments. All calves received their mothers' colostrum for 3 days.

[3] The normal growth referred to here is the average attained at 6 months of age by calves fed whole and skim milk as in experiment 1, group III, the calves being allowed grain and U. S. No. 1 alfalfa hay.

[4] These 4 calves continued to grow longer than those in group I above.

[5] When, at 7 months of age, milk from pasture-fed cows was substituted in the ration of 1 of these calves for the milk previously fed, the calf increased quite strikingly in rate of growth. From 4 to 7 months of age it had gained 137 pounds, or 65 percent of normal; for the next 4 months, on the milk from pasture-fed cows, it gained 233 pounds, or considerably above the normal for this period.

[6] Skim milk is practically free of vitamin A.

[7] The results in experiment No. 3, groups II and III and in No. 4 are from unpublished data.

[8] This calf ate a negligible amount of hay and therefore is comparable with those in experiment No. 1, group I, in vitamin A intake.

and 3, the calves were fed a grain-hay mixture low in vitamin A so that the differences in growth produced by the differences in the vitamin activity of the various milks and supplements could be observed.

The results in table 12 do not give data that permit accurate calculation of the minimum vitamin A requirements of these young growing calves, and such data are not available in the literature for calves of this age; but the results do indicate that this requirement is very considerable, that failure to meet it is very detrimental, and that such failure may occur with ordinary feeds used in practice. According to the severity of the deficiency, there may be slow growth, general weakness and scours, or pneumonia and death. Blindness was frequent among these calves, but its occurrence could not be correlated with the severity of the deficiency.

The effect on growth of a failure to feed sufficient vitamin A with a low-grade

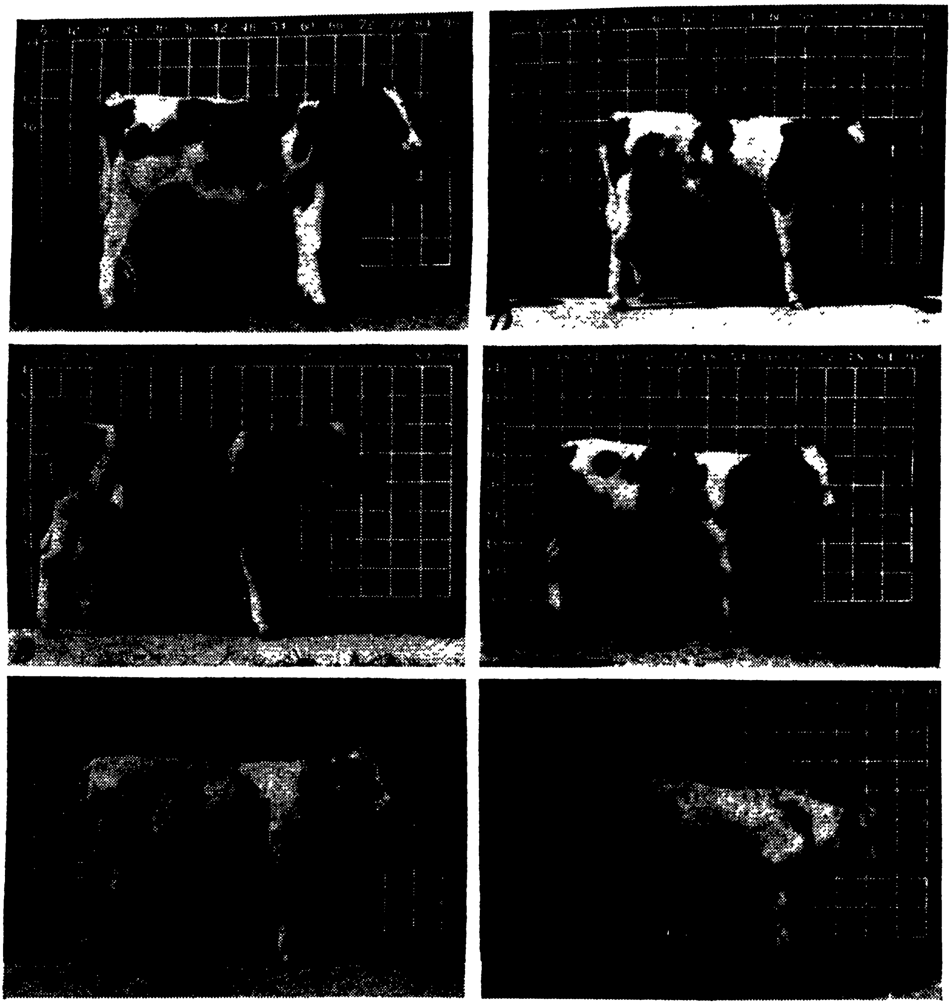

Figure 3.—Calves need vitamin A or its precursor, carotene, for normal growth. (The squares behind each calf are 6 inches each.) *A*, Weight at 6 months, 406 pounds; fed whole milk plus cod-liver oil. *B*, Weight at 6 months, 400 pounds; fed skim milk after third day, plus cod-liver oil. *C*, Weight at 6 months, 388 pounds; fed whole milk and skim milk plus cod-liver oil. *D*, Weight at 6 months, 283 pounds; fed whole milk, no cod-liver oil. *E*, Weight at 6 months, 287 pounds; fed whole milk and skim milk, no cod-liver oil. *F*, Weight at 6 months, 234 pounds; fed whole milk and skim milk, no cod-liver oil.

hay is clearly illustrated in figures 3 and 4. The six calves shown in figure 3 all received late-cut No. 3 timothy hay, very low in carotene, and a high-protein grain mixture. The whole milk and skim milk fed the calves was from cows getting various roughages, as follows: *A*, No. 3 timothy hay; *D*, No. 1 alfalfa hay; *E* and *F*, pasture; *C*, No. 3 timothy hay; and *B*, mixed herd milk. Calves *C*, *E*, and *F* were fed whole milk for 20 days with a gradual change to all skim milk by 30 days. Calf *E* became blind.

The Holstein calves shown in figure 4 are both 6 months of age. They received a ration of skim milk after the third day with late-cut timothy hay, a good grain mixture, and grated yellow garden carrots as the vitamin A supplement. The smaller calf received 60 grams of grated carrots daily while the larger calf received 180 grams. Each calf is representative of a group of three that were fed the same ration. The three calves receiving the larger amount of grated carrots made an average daily gain in weight of 1.4 pounds. Three similar calves fed the smaller amount of carrots gained an average of only 0.7 pound daily.

Apparently, from the data in table 12, the vitamin A requirements for normal growth of young calves may be met practically completely by feeding the young calf whole milk from cows on pasture or vitamin A-potent supplements such as cod-liver oil or carrots, or the older calf roughages rich in vitamin A such as a good-quality green hay or silage made from green material. Or these requirements may be met by any combination of these methods, such as feeding the calf a good hay or silage potent in vitamin A in addition to milk from cows similarly fed.

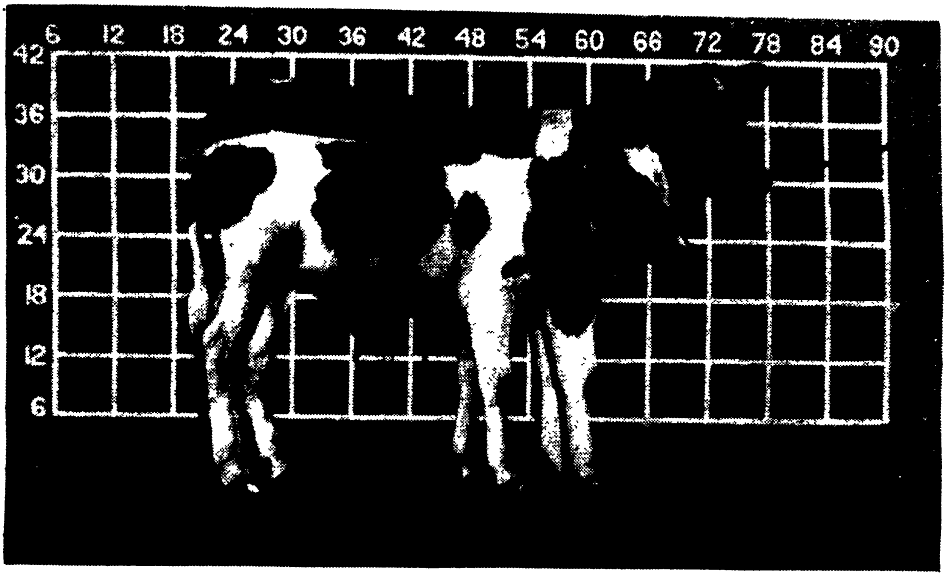

Figure 4.—The effect of insufficient amounts of vitamin A on the growth of calves. At 6 months of age, the larger calf, which received about 7 ounces of grated carrots daily, weighed 329 pounds, compared with 170 pounds, the weight of the other calf at the same age. The smaller calf received only a third as much grated carrot in its ration.

Particularly during the skim-milk feeding period, good green hay or some other source of vitamin A should be fed to calves. Garden carrots are a good source of carotene and may be fed during this period. They may be grated into the milk of young calves or fed chopped to the older animals. Cod-liver oil is a very satisfactory supplement when not fed in excess. A good green alfalfa-leaf meal is also valuable under these conditions; and the vitamin A requirements of calves may be met by pure carotene dissolved in oil. It is interesting to note that when the vitamin A requirements of calves are met, they may be reared after 3 days of age without further feeding of whole milk and make normal gains in weight as measured by the weights at 6 months of age.

Guilbert, Miller, and Hughes (*447*) of the California Agricultural Experiment Station have reported that the vitamin A requirements of the bovine at all ages may be met by about 7.55 micrograms of vitamin A from cod-liver oil or about

29 micrograms of carotene from plant materials daily per kilogram (2.2 pounds) of body weight. According to these data the vitamin A needs of a 3-month-old Holstein calf would be supplied by about 1 milliliter of cod-liver oil or by about 30 or 40 grams daily of garden carrots or alfalfa-leaf meal. These California experiments were carried out with animals that were 7 months old or older; and, insofar as the writer is aware, no published evidence is at hand to show that the results are applicable to such rapidly growing animals as were used in the experiments reported in table 12, nor is anything known about the conditions in feeds that may influence the utilization of vitamin A or its precursors. It will be noted that the calves in experiment No. 3, group II, made very poor growth and that two of these animals had eye lesions; yet, according to the analyses of the carrots, these animals were fed more carotene per kilogram of body weight than would be required according to the California results. Hardly normal growth was attained with three times this quantity of carrots—that is, the quantity used in experiment No. 3, group II—and certainly not less than this amount should be fed.

As indicated in table 12, calves may grow normally when their vitamin A requirements are supplied by 10 or 20 milliliters (2 or 4 teaspoonfuls) of cod-liver oil; and they have been raised to calving on these amounts. Until more definite information is at hand as to the minimum requirements of these growing calves, and until market standards are adopted for animal-feeding oils it may be well to use 20 milliliters (4 teaspoonfuls) daily of cod-liver oil when calves are fed skim milk and roughages low in vitamin A. The main sources of vitamin A in the calf rations usually fed are whole milk, green hay, and silage made from green material. Whether or not it is necessary to use vitamin A supplements depends upon the quality of the milk and the quality of the roughage in the calf ration.

Calves kept in the dark and fed rations low in vitamin D may suffer from a deficiency of that vitamin. Bechdel (*80*) describes the symptoms as "decreased growth rate, abnormal bone development, swollen joints, slight paralysis of the rear quarters, and a bowed back." Vitamin D assists in the deposition of minerals in the bones. Bechdel in the same publication gives the ash or mineral content of the bones of his experimental calves. The ash in the femora on a fat-free basis was about 54 percent in the calves with rickets. Calves of the same age on the same ration that were irradiated with ultraviolet light or given cod-liver oil as a source of vitamin D had femoral bones with about 59 or 60 percent of ash on the same fat-free basis.

Mitchell and McClure (*803*) state: "Farm animals of all types generally receive an adequate supply of vitamin D by exposure to the sun's rays. Depending on the intensity of the sunlight and its concentration of ultraviolet rays, which vary with the season, time of day, and atmospheric contamination, exposures of 10 to 30 minutes daily are ordinarily sufficient." Bechdel and collaborators (*77*) have recently reported that the minimum level of vitamin D for growth, well-being, and proper calcification of the bones of calves kept in the dark from birth to 7 months is approximately 300 United States Pharmacopoeia units per day per hundredweight. This requirement can easily be supplied with normal calf rations even in the absence of sunlight. Bechdel had previously reported (*80*) that though calves developed a mild rachitic condition when kept in the dark and fed 1 pound of sun-cured or 2½ pounds of artificially dried alfalfa hay, there were no rickets when 2½ pounds of sun-cured alfalfa was fed daily. Calves that get a reasonable amount of sunshine and normal rations should need no additional vitamin D from cod-liver oil or irradiated yeast. Calves little exposed to sunlight and receiving dehydrated alfalfa or green hay that has been cured almost without sunlight might be slightly deficient in this vitamin.

It has been reported that the vitamin B complex, including vitamin B_1 and riboflavin (vitamin G or B_2), is abundantly supplied in all usual calf rations. Eckles et al. (*302*) in 1924 reported that the addition of yeast, which is rich in both vitamin B_1 and riboflavin, to normal calf rations including whole or skim milk, grain, and hay did not increase the rate of gain between 14 and 180 days of age. In 1926, Bechdel et al. (*75*) reported that calves grew normally when started between 112 and 179 days of age on rations too low in vitamin B to support rat growth. It was assumed that the calf requirement was very low or that the necessary factors were formed by the action of bacteria in the stomach of the animal. In 1928, Bechdel et al. (*79*) demonstrated that older cattle at least do form these factors in their paunch. The paunch content of a cow that had been raised and was continued on a ration deficient in vitamin B proved very potent in that factor when fed to rats. To what extent the calf can produce the vitamin B complex before the paunch is developed was not shown.

Recently, however, Newman and Savage (*852*) have suggested that some part of the vitamin B complex may be deficient in certain milk substitutes or calf starters that are being prepared at Cornell University. In their experiments the calves were fed only 350 pounds of whole milk, in gradually reduced amounts from birth to 8 or 10 weeks of age, when milk feeding was stopped. A dry calf starter was fed to the calves to a maximum of 4 pounds daily. The basal calf starter was composed of ground yellow corn, 32.25 parts; rolled oats, 28; wheat bran, 10; linseed meal, 5; white fish meal, 3; dried skim milk, 20; bonemeal, ½ part; limestone, ½; salt, ½; and codliver oil, ¼. Fine-stemmed, leafy mixed hay was fed. Groups to which this starter was fed with yeast included, even when the dried skim milk was reduced to 10 parts, made larger gains than did the group getting the basal starter without yeast. In these experiments the value of the yeast seemed quite evident, yet the need of it as a source of either vitamin B, or riboflavin is not clear. Since the ration contained dried skim milk, corn meal, wheat bran, and leafy hay of good quality, the calves must have received quite large amounts of vitamin B_1 and riboflavin without the addition of yeast. The actual factor in the yeast that promoted growth in these experiments was not determined.

Water

Water makes up over 60 percent by weight of the calf's body and over 75 percent of the body tissues formed during growth. It is used by the calf in the processes of food digestion and assimilation, and in the removal of waste products. Water also helps to regulate body temperature. Supplying an abundance of pure fresh water to young dairy stock is therefore of the utmost importance.

The water requirement of calves from birth to 6 months of age has been investigated by Atkeson, Warren, and Anderson (*46*) at the Idaho Agricultural Experiment Station. Data from this investigation are presented in table 13. The total water consumption per calf, including that in the feed, was about the same for calves of the same age and weight raised by different methods of feeding. The increase in water requirements with age was almost directly proportional to increase in weight. More water was required per 100 pounds of body weight in warm weather than in cool. In relatively cool weather the calves (mostly less than 3 months of age) consumed 7.5 to 9 pounds of water daily, including that in the feed, per 100 pounds of body weight. In relatively warm weather the calves (mostly 3 to 6 months of age) consumed 10 to 11 pounds daily per 100 pounds of body weight.

TABLE 13.—*Water consumption per calf daily from 3 to 24 weeks of age* [1]

Age (weeks)	Calves fed liquid milk for 6 months					Calves fed liquid milk for 5 weeks [2]				
	Body weight	Water consumption				Body weight	Water consumption			
		Water drunk	In milk	In hay and grain	Total		Water drunk	In milk	In hay and grain	Total
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
3	106.8	0.01	9.13	0.03	9.17	120.0	0.56	10.36	0.03	10.95
4	121.3	.07	9.85	.07	10.03	128.0	1.50	10.30	.06	11.86
5	129.2	.24	9.14	.10	9.48	139.6	1.49	10.07	.10	11.66
6	135.7	.74	9.31	.16	10.21	150.2	4.11	5.39	.23	9.76
8	157.7	2.19	10.17	.26	12.62	172.9	11.26	.69	.53	12.48
10	181.1	4.31	10.83	.37	15.51	195.3	15.26	--------	.73	15.99
12	204.7	6.60	11.17	.46	18.23	218.8	18.63	--------	.83	19.46
16	256.3	12.91	11.80	.57	25.28	272.0	27.09	--------	1.04	28.13
20	317.5	18.10	13.34	.73	32.17	321.8	30.73	--------	.99	31.72
24	387.5	25.23	13.34	.93	39.50	373.7	38.96	--------	1.24	40.20

[1] Data adapted from tables 1 and 2, Water Requirements of Dairy Calves (*46*).

[2] Raised on dry-fed grain mixtures, liquid milk being eliminated between the sixth and eighth weeks.

It seems probable that the water requirements would be about the same for calves of different dairy breeds having the same body weight. The water requirements of rapidly growing heifers may be about the same per 100 pounds of body weight as those of calves. When growth slows down, less water may be required since the average total water requirement of dry dairy cows was found by Atkeson and Warren (*45*) to average only 6.2 pounds daily per 100 pounds of live weight.

During the winter months, calves receiving liberal quantities of liquid milk may make good growth without additional water, but by the time they are 2 months old they should have all the water they will drink. During warm weather a lack of water may result in discomfort and slow down feed consumption and rate of growth. Rupel (*993*) reported an experiment at the Wisconsin Agricultural Experiment Station, conducted in warm weather, in which the calves in one group were watered twice daily, while those in another group received no water. Both groups received 14 pounds of skim milk per calf daily and all the hay and grain they would eat. The calves receiving water drank somewhat more water than milk, ate twice as much hay and nearly one-third more grain, and gained 1.80 pounds each daily as compared with a daily gain of only 1.36 pounds for the calves receiving no water.

Calves old enough to run together should be supplied with an abundance of pure water. This may be provided from a conveniently located water trough or from a drinking cup.

VARIATIONS IN THE COMPOSITION OF MILK

by P. A. Wright, E. F. Deysher, and C. A. Cary[1]

THERE is more similarity between different kinds of milk than there is between milk and any other food. Yet analysis shows that there are real differences not only in the milk of different species of animals, but in the milk of different breeds of cows; of different individuals in the same breed; and between the morning and evening milk of the same cow, or even the milk from different quarters of the udder. This article gives data on these differences; discusses the relation between the protein, fat, and energy values in milk; and shows how readily feed flavors and odors are transmitted to milk.

DIFFERENCES IN THE COMPOSITION OF THE MILK OF DIFFERENT SPECIES

THE PERCENTAGES of the chief constituents of milk differ with various species of mammals. For the various kinds of milk used for human food in different parts of the world, these percentages are given in table 1.

The most important characteristics of human milk are its low protein, low ash, and high lactose percentages. The first set of values for human milk given in table 1, consists of averages of 1,154 analyses representative of the entire lactation period. The second set, reported by other workers, shows only two-thirds as great a percentage of protein, possibly because in this case the milk was not sampled until the women had been in lactation for at least 2 months.

An examination of table 2 indicates that the ratio of noncasein protein to casein in human milk is nearly 4 times the corresponding ratio in cow's milk, and that the ratio of nonprotein nitrogen to casein nitrogen in human milk is almost 13 times that in cow's milk.

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With the exceptions of the sections headed Differences in the Composition of the Milk of Different Species; Relation Between the Fat, Protein, and Energy Values; Effect of Diet on Composition; and Transmission of Feed Flavors and Odors and of Drugs to Milk, and of table 4, the material in this article is taken by permission with slight modification from Fundamentals of Dairy Science by Associates of L. A. Rogers (*42*),[2] chapter 1. The parts used in this article were revised by P. A. Wright and E. F. Deysher for the second edition of the book mentioned.

[2] Italic numbers in parentheses refer to Literature Cited, p. 1075.

TABLE 1.—*Average composition of milks of certain mammals*

Species	Water	Protein [1]	Fat	Lactose	Ash
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Woman	87.43	1.63	3.75	6.98	0.21
Do	87.68	1.05	4.37	6.79	.18
Cow	86.21	3.77	4.45	4.86	.72
Do	87.90	3.13	3.65	4.50	.72
Goat	87.14	3.71	4.09	4.20	.78
Ewe	82.90	5.44	6.24	4.29	.85
Egyptian buffalo	82.09	4.16	7.96	4.86	.78
Chinese buffalo	76.80	6.04	12.60	3.70	.86
Philippine carabao	78.46	5.88	10.35	4.32	.84
Camel	87.61	2.98	5.38	3.26	.70
Mare	89.04	2.69	1.59	6.14	.51
Do	90.23	2.30	.78	6.42	.44
Ass	89.70	2.10	1.50	6.40	.30
Reindeer	63.30	10.30	22.46	2.50	1.41

[1] 6.38 × nitrogen.

TABLE 2.—*Distribution of nitrogen in human and in cow's milk*

Kind of milk	Total nitrogen	Casein nitrogen as percentage of total nitrogen	Noncasein protein nitrogen, as percentage of total nitrogen	Nonprotein nitrogen as percentage of total nitrogen
	Percent	*Percent*	*Percent*	*Percent*
Human	0.1749	34.3	30.0	35.2
Cow's	.497	76.1	18.0	5.9

The first set of figures for cow's milk in table 1 is from analyses made at the Illinois Agricultural Experiment Station and represents 1,998 samples obtained during 198 whole lactation periods from 14 Ayrshire, 16 Guernsey, 19 Holstein, and 15 Jersey purebred cows and 66 Guernsey-Holstein crossbred cows. The averages for protein, fat, and lactose are definitely higher than those in the second set of figures, which represent 208 herd samples obtained from dairy farms in New York.

Goat's milk appears to be very similar in composition to cow's milk. The averages given represent analyses by 18 investigators of the milk of at least 326 goats.

The averages for ewe's milk are from analyses of the milk of two ewes at regular intervals during the whole lactation period.

Many species of mammals bearing the name of buffalo, or closely related thereto, are used as dairy animals. The milk of the Egyptian type of buffalo is used for food in many sections of southern Europe as well as in parts of Africa and Asia. The averages are based on analyses of 61 composite samples, each representing the milk of 6 animals. The values for the milk of the Chinese water buffalo are averages of frequent analyses of the milk of 30 animals over a period of 18 months. The averages for the milk of the Philippine carabao are based on individual samples from 19 animals. Analyses of the milk of these 3 different species of buffaloes are included in the table because of the large variation in total solids—principally fat. All of these milks contain a much greater percentage of fat and protein than does cow's milk.

Camel's milk is somewhat higher in percentage of fat and lower in lactose and protein than cow's milk. The averages given in table 1 were computed from the reports of several analysts.

Mare's milk is used for food most commonly in parts of western Asia. It is especially low in solids, protein, fat, and ash, and high in lactose. The first averages found by Linton for 104 samples of noncolostral milk from mares in Great Britain are higher in percentages of total solids, protein, fat, and ash, and lower in percentage of lactose, than the averages calculated from analyses reported by Hildebrandt in Germany.

Ass's milk, much used for food in parts of Europe, is quite similar to mare's milk. The composition given is the average of the results of several analysts.

Of all the natural milks used for food by man, that of the reindeer is the most concentrated. The percentage of lactose constitutes an exception to this general statement, since reindeer's milk contains only about one-half the percentage of lactose present in cow's milk.

DIFFERENCES IN THE COMPOSITION OF COW'S MILK

Practically all of the milk sold in the raw or manufactured form in this country is from the cow. Even cow's milk is not a uniform article of commerce. The differences in composition—for example, in fat content—which are principally due to differing environment and inheritance, are of such magnitude that many dairies standardize their milk by mixing batches from different farms or breeds of cattle.

DIFFERENCES DUE TO BREED

Variations due to breed are of the greatest magnitude and will be considered first. The breeds represented in the United States by the greatest number of dairy cows are in increasing order Ayrshire, Guernsey, Holstein, and Jersey. The Shorthorn, though often considered a dual-purpose breed, should possibly be included here because great quantities of milk are produced from grade Shorthorn cows, especially in the butter-producing States of the Mississippi Valley.

The figures in table 3 for the first four breeds are averages obtained by Overman, Sanmann, and Wright (*889*) at the Illinois Agricultural Experiment Station. The figures for the Shorthorn breed are averages of analyses by several investigators, reported by Eckles and Shaw at Missouri.

TABLE 3.—*Average composition of milk of five breeds of cows*

Breed	Water	Total solids	Fat	Protein	Lactose	Ash
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Guernsey	85. 13	14. 87	5. 19	4. 02	4. 91	0. 74
Jersey	85. 31	14. 69	5. 18	3. 86	4. 94	. 70
Ayrshire	86. 89	13. 11	4. 14	3. 58	4. 69	. 68
Holstein	87. 50	12. 50	3. 55	3. 42	4. 86	. 68
Shorthorn	87. 43	12. 57	3. 63	3. 32	4. 89	. 73

Table 3 shows that there is considerable difference in total solids of the milk of the Guernsey and Jersey breeds on the one hand and of that of the Ayrshire, Holstein, and Shorthorn breeds on the other. More than half of this difference is in the fat percentage, the rest being mostly in the protein. Except for the Ayrshire breed the lactose percentages in the milks are remarkably constant.

Table 4 gives the average production of milk and butterfat of the cows having official yearly records in the breed associations.

TABLE 4.—*Average yearly production of milk and butterfat of cows of different breeds that had official yearly records to January 1, 1938* [1]

Breed	Advanced register or register of merit				Herd-improvement test			
	Records of cows and heifers	Milk	Butterfat		Records of cows and heifers	Milk	Butterfat	
			Quantity	Test			Quantity	Test
	Number	*Pounds*	*Pounds*	*Percent*	*Number*	*Pounds*	*Pounds*	*Percent*
Ayrshire	[2] 9,022	10,446	416	4.0	20,571	8,351	338	4.0
Brown Swiss	939	13,643	548	4.0	984	8,577	352	4.1
Guernsey	49,212	10,095	502	5.0	5,229	8,629	425	4.9
Holstein-Friesian	[3] 56,007	16,005	546	3.4	[4] 52,369	11,101	380	3.4
Jersey	56,789	8,556	459	5.36	27,364	6,797	359	5.3

[1] Data from U. S. Department of Agriculture Farmers' Bulletin 1443 (*864*).
[2] Includes 1,952 305-day records.
[3] Includes 15,354 10-month records.
[4] Up to Oct. 1, 1937.

RELATION BETWEEN THE FAT, PROTEIN, AND ENERGY VALUES

The concentration of fat in cow's milk may be taken as a rough indication of its protein and energy value as a food and of the feed protein and energy required for its production. The fat and protein concentrations in cow's milk vary; they may under some unusual conditions vary independently of each other but in general there is a roughly constant relation between them. In addition to this the concentration of lactose, which also contributes materially to the energy value of milk, is relatively quite constant. There are three series of analyses of cow's milk in which these relations have been particularly studied in this country.

The first extensive series is that of Haecker (*455*) at the University of Minnesota. He determined the concentrations of fat, carbohydrate, and protein in 543 samples of cow's milk. His results have been used as the basis of several feeding standards for milk cows. In fact, the Haecker standard is said to be the first in which the composition of the milk was taken into account in calculating the feed allowances of milking animals. Armsby (*32*) calculated the total energy value of the milks analyzed by Haecker, taking 1 gram of fat as equivalent to 9.23 calories, 1 of protein to 5.7, and 1 of lactose to 4.1; and Gaines (*404*) has expressed the relation between the fat and protein in these milks by the following equation:

Percentage of protein in the milk $= 1.46 + 0.4$ of the percentage of fat---(1)

The second larger series of analyses to be considered here were done at the University of Illinois. Overman and Sanmann (*888*) report the fat, carbohydrate, protein, and energy content of 212 samples of milk; and Overman, Sanmann, and Wright (*889*) determined the fat, carbohydrate, and protein concentrations of 1,999 samples. Overman and Gaines (*887*), using constants determined from the milks of Overman and Sanmann in which the total energy value was determined, calculated the energy value of the 1,999 milks from the analyses of Overman, Sanmann, and Wright; and Mitchell (*795*) has expressed the relation of fat to protein in these milks as follows:

Percentage of protein in the milk = 2 + 0.4 of the percentage of fat-- (2)

From the above calculations Overman and Gaines conclude that the energy content of milk containing 4 percent of fat is approximately 750 calories per kilogram, or 341 calories per pound; and they suggest that with any breed of cows the weight of 4-percent milk containing the same amount of energy as the milk yielded by the particular cows in question may be calculated from the following equation:

Weight of 4-percent milk equivalent in energy value = 0.4 of the weight of the milk yielded + 15 times its fat content expressed in percent---(3)

After analyses of many hundred samples of milk had been made, workers at the Ohio Agricultural Experiment Station (*868, p. 17*) came to the conclusion that "in samples of milk testing 2.78 percent of butterfat the percentage of protein and fat are approximately equal. Above this point the protein increases approximately 0.42 times as fast as the fat." This relation may be expressed as follows:

Percentage of protein in the milk—2.78 + 0.42 (percentage of fat, 2.78)--(4)

TABLE 5.—*Relation between the protein, fat, and energy values of milk*

Fat (percent)	Overman, Sanmann, and Wright [1]			Haecker			Ohio analyses, protein calculated
	Protein		Energy calculated [3]	Protein		Energy calculated	
	Found	Calculated [2]		Found	Calculated		
	Percent	*Percent*	*Calories per pound*	*Percent*	*Percent*	*Calories per pound* [4]	*Percent*
3.0	3.07	3.20	290	2.68	2.66	278	2.87
3.5	3.39	3.40	315	2.81	2.86	306	3.08
4.0	3.54	3.60	341	3.08	3.06	336	3.29
4.5	3.83	3.80	367	3.27	3.26	365	3.50
5.0	4.02	4.00	392	3.45	3.46	390	3.71
5.5	4.18	4.20	418	3.65	3.66	415	3.92
6.0	4.50	4.40	443	3.82	3.86	440	4.13
6.5	[5] 4.63	4.60	469	4.02	4.06	467	4.34
7.0	4.91	4.80	494	4.22	4.26	492	4.55

[1] Average for all breeds for which analyses are given.
[2] Calculated, using Mitchell's equation given in text.
[3] Calculated, using 341 calories per pound for 4-percent milk and equation in text for calculating the 4-percent milk equivalent in energy content to that yielded.
[4] Calculated by Armsby (*32, p. 511*).
[5] Data for Jersey breed omitted.

The above-mentioned data are shown in table 5. Although in each series of results the percentage of fat may be taken as indicative of the protein and energy value of the milk, it will be noted that in the

Haecker milk the percentage of protein is much lower for the same percentage of fat than in the milks analyzed by Overman, Sanmann, and Wright. The difference for the same fat content is on the average 0.54 percent; that is, if the protein in the milk analyzed by Overman, Sanmann, and Wright is 3.99 percent, that for milk of the same fat content analyzed by Haecker would be 3.45 percent. This condition makes a difference of 9 to 18 percent in the calculated nutritive value of milks of the same fat content, depending upon which of the milks is used as a basis of calculation. It also makes the same difference in the calculated protein requirements of the cow. The results with the Ohio figures are intermediate in this respect. It should be noted that the energy values of milk given in table 5 are for the total energy that it would yield if completely burned in a calorimeter. This would not be the metabolizable energy of the milk, as the protein when burned in a calorimeter yields about 5.7 calories per gram, whereas when oxidized in the animal body it yields only about 4.1 calories per gram.

DIFFERENCES DUE TO INDIVIDUALITY

Within a herd of cows of a single breed there may be considerable variations in composition of milk between individuals, even though all have the same care, feed, and environment. These individual differences are probably due to many factors, of which the principal one is undoubtedly inheritance. The variations are chiefly in percentages of fat and of protein; as the percentage of fat increases, the percentages of protein, ash, total solids, and solids-not-fat increase, but the percentage of lactose—except in Ayrshire milk decreases.

DIFFERENCES BETWEEN ONE MILKING AND ANOTHER

If the intervals between milkings are the same, the percentages of protein and lactose in milk from the same cow vary very little, but the morning milk is usually richer in fat than the evening milk, sometimes by almost 2 percent. The more frequent the milkings, the greater the variation in fat.

VARIATIONS IN COMPOSITION DURING MILKING

During milking, the percentage of fat increases markedly, and unless the udder is carefully stripped, the milking will not be truly representative with respect to fat. The difference between the fore milk and the strippings is only in the fat. Table 6 shows typical variations in fat.

TABLE 6.—*Variations in fat content of milk during milking*

Portion of milking period	Cow No. 1	Cow No. 2	Cow No. 3	Portion of milking period	Cow No. 1	Cow No. 2	Cow No. 3
	Percent	*Percent*	*Percent*		*Percent*	*Percent*	*Percent*
First	0.90	1.60	1.60	Third	5.35	4.10	5.00
Second	2.60	3.20	3.25	Fourth (strippings)	9.80	8.10	8.30

VARIATIONS IN DIFFERENT QUARTERS OF THE UDDER

There are distinct differences among samples of milk from different quarters of the udder, not only in gross composition, but also in the percentage of calcium in the ash and in the composition of the fat. However, no regularity has been found in these variations.

INFLUENCE OF SUCCESSIVE PHASES OF THE LACTATION PERIOD

The secretion of the mammary glands for the first few days of lactation is known as colostrum and is quite different from the later normal secretion. Colostrum has a strong odor and a bitter taste and contains a remarkably high percentage of globulin. Table 7 shows the gradual change from colostrum to normal milk.

TABLE 7.—*Changes in composition during the transition from colostrum to normal milk*

Time after calving (hours)	Casein	Albumin[1]	Fat	Lactose	Ash	Total solids
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0	2.65	16.56	3.54	3.00	1.18	26.93
10	4.28	9.32	4.66	1.42	1.55	21.23
24	4.50	6.25	1.75	2.85	1.02	19.37
48	3.25	2.31	4.21	3.46	0.96	14.19
72	3.33	1.03	4.08	4.10	.82	13.56

[1] This column gives the albumin fraction, which includes globulin. Except for a fraction of a percent of albumin this is undoubtedly all globulin.

The milk of the month following the colostral stage is characterized by a slightly higher percentage of the albumin fraction and of fat than occurs during the long midstage of relatively constant composition and yield. During the final stage, when the daily quantity of milk is decreasing, the casein and fat percentages both increase somewhat.

EFFECT OF GESTATION AND OF DISEASE

Gestation exerts no direct influence on the composition of cow's milk but may hasten the end of lactation, which in itself causes marked changes in the composition.

Milk composition may undergo considerable change from the normal when the cow becomes diseased.

EFFECTS OF DIET ON COMPOSITION

For the effect of diet on the concentrations of protein, fat, and lactose in milk, see the article on Glands, Hormones, and Blood Constituents—Their Relation to Milk Secretion (p. 685). Except in the case of iodine, it is not practical to try to alter the concentrations of the mineral constituents in milk, and even in this case it is not economical.

THE MINERAL CONSTITUENTS OF COW'S MILK

Ash analyses for cow's milk are given in table 8. The values for ferric oxide are much larger than those determined more recently on the milk itself without ashing, as will be seen from the following detailed discussion.

The trends in the variation of ash constituents during the lactation period are as follows: Potassium is present in smaller quantities in colostrum than in later milk. It reaches a maximum in the second month of lactation and then declines, slowly at first, more rapidly during the last 2 months. Sodium decreases slightly during the first half of the lactation period and rises markedly during the second half. However, it is subject to considerable variation. Calcium is higher in colostrum than in normal milk and remains about the same after the normal quantity has been reached until the third month before the close of lactation, when it rises slowly. Chlorine is fairly constant during the lactation period, exhibiting a small constant rise throughout. Phosphoric acid is higher in colostrum than in normal milk, declining slowly at first and then more rapidly.

TABLE 8.—*The composition of the ash of milk* [1]

Mineral	Ranges of values found by several European investigators	Values reported by Babcock [2]	Mineral	Ranges of values found by several European investigators	Values reported by Babcock [2]
	Percent	*Percent*		*Percent*	*Percent*
Potassium	14.6 to 23.9	20.8	Iron	0.035 to 0.280	0.091
Calcium	14.2 to 20.5	14.3	Phosphorus	9.44 to 12.8	10.6
Sodium	1.93 to 8.2	7.4	Chlorine	12.2 to 16.4	14.3
Magnesium	0.72 to 3.01	1.46	Sulfur	1.53 to 2.46	2.30

[1] Data given here are calculated from data in (*42*), p. 21.
[2] In Leach (*667, p. 111*).

MINOR INORGANIC CONSTITUENTS IN MILK

In addition to the mineral elements already discussed, milk contains small amounts of copper, iron, zinc, aluminum, manganese, and iodine. The quantities of some of these can be determined by microanalytical methods. These elements have been shown to be important from a physiological and nutritional standpoint. For instance, iron is necessary in hemoglobin, but copper must be present if hemoglobin is to be formed. Manganese has been reported as affecting growth and some phases of reproduction. Iodine is important for the normal functioning of the thyroid gland.

Several investigators have made spectrographic examinations of milk ash and have found, in addition to those already listed, numerous other elements present in small but definite traces.

Copper

Supplee and Bellis (*1108*), analyzing freshly drawn milk of a large number of cows on differing rations, found the proportion of copper varying from 0.2 to 0.8 parts per million, with no apparent correlation between copper content and type of ration. Quam and Hellwig (*938*) found 0.26 to 0.49 parts per million of copper in cow's milk, practically the same proportion in sheep's milk, but slightly less in goat's milk. Davies (*267*), found 0.05 to 0.65 parts per million in 15 samples of fresh milk. Zondek and Bandmann (*1278*) found 0.15 to 0.20 parts per million in cow's milk and 0.5 to 0.6 in human milk. Elvehjem et al. (*329*) analyzed 13 samples of herd milk from widely different sections of the United States and found from 0.123 to 0.184 parts per million with an average of about 0.15. They believe that some of the other figures reported are too high because of contamination of the sample with copper during analysis.

Hess and Unger (*511*) have shown that, if milk is contaminated with copper, its vitamin C activity is reduced. Davies (*267*) found that, when the copper exceeds 1.5 parts per million, milk of otherwise good quality developed an oiliness, even when properly refrigerated.

The effects of manufacturing processes on the proportions of copper and iron in dairy products have been studied by Davies (*267*) and by Williams (*1230*). They found that pasteurization and sterilization increase the percentage of both these metals in milk. The most striking effect was noted in cheese made in copper vats, the cheese containing in some cases as much as 18 parts per million of copper.

Iron

Analyses of samples of cows' milk from several different sources have given results ranging from 1 to 4.5 parts per million of iron and averaging about 2.5. Higher values calculated from ash analyses are probably due to faulty methods of analysis The proportion of iron in human milk and in goat's milk is the same as that in cow's milk.

Zinc

The proportion of zinc in 12 samples of market milk was found by Birckner (*103*) to be 3.6 to 5.6 parts per million. Sato and Murata (*1010*) found from 2.94 to 4.12 parts per million in normal herd milk. They found little difference in the proportions of zinc in human milk, cow's milk, and sheep's milk. Colostral milk was found to contain about 13 parts per million, a marked decrease taking place during the first few days of the lactation period. Throughout the main part of the lactation period, the proportion of zinc remained constant, but increased at the end.

Manganese

The proportion of manganese in normal milk has been found to be 0.02 to 0.06 parts per million. Sato and Murata (*1010*) reported 0.10 to 0.21 parts per million in cow's colostrum, and 0.041 to 0.115 in sheep's milk. Kemmerer and Todd (*617*) found 0.082 parts per million in goat's milk.

Iodine

Iodine is present normally in milk, occurring in small but variable quantities. It is easily transmitted to milk from the feed. The amounts reported vary from 0.001 to 0.275 parts per million. Scharrer and Schwaibold (*1014*) dried a sample of normal cow's milk and determined the distribution of the iodine. They found 4.5 percent of the total in the fat, 31 in the protein, 60.5 in organic combination in the serum, and 4 percent in inorganic combination in the serum. Milks having 1 to 14 parts per million of iodine have been produced by adding organically combined iodine to the feed of the cow. Organic iodine in proportions as high as 20 parts per million imparts no unpleasant taste or odor to milk. Inorganic iodides are also effective, but the feeding of compounds containing iodine in order to produce a milk rich in it is not economical. Colostral milk contains a comparatively large proportion of iodine, but this decreases to the normal amount within 36 hours after parturition. Remington and Supplee (*956*) analyzed samples of dried milk from several sections of the United States; 117 samples from South Carolina contained 0.143 to 1.872 parts of iodine per million, with a mean of 0.572; 9 samples from New

York contained 0.131 to 0.392, with a mean of 0.265; 6 samples from Wisconsin contained 0.171 to 0.395 parts per million, with a mean of 0.322.

MINOR ORGANIC CONSTITUENTS OF MILK

In addition to the major organic constituents of cow's milk, there are numerous other organic constituents present in small amounts, including the vitamins, various enzymes, steroid materials, phospholipids, pigments, etc., the functions of which are in many instances unknown.

TRANSMISSION OF FEED FLAVORS AND ODORS AND OF DRUGS TO MILK[3]

Feed and weed flavors are frequently encountered in milk. It was formerly believed that these flavors were absorbed by the milk after it was drawn from the cow, but experimental work has shown that they are transmitted to milk mainly through the body of the cow.

Babcock (*52*) by feeding garlic to cows, showed that a garlic flavor and odor could be detected in milk drawn 1 minute after the garlic was fed and that 10 minutes afterward the milk had a strong garlic flavor and odor. It was impossible for the milk to absorb the garlic flavor since it was drawn in an atmosphere free of garlic odor.

In a further test, cows were forced to inhale garlic odor for 10 minutes and were then milked at varying intervals. The experiment was carried on outside of the milking barn where there was no chance of a garlic-permeated atmosphere surrounding the milk, and the cows were given no possible chance to eat any of the garlic. When the cows were milked 2 minutes after inhaling garlic for 10 minutes, garlic flavor and odor were very pronounced in the milk. It had therefore been absorbed from the lungs into the blood stream and thence into the udder. That flavors are absorbed by the blood is shown by the fact that a garlic odor was readily perceived in samples of blood drawn from the jugular veins of cows 30 and 45 minutes after they had consumed garlic.

It has also been noted that certain drugs and medicines fed to cows pass through the body and are found in the milk. Fröhner, as reported by Allen (*16, p. 972*), states that camphor, turpentine, camomile, aloe, arsenic, lead, and tartar emetic may be transmitted to milk, sometimes in poisonous quantities. Mercury and copper may also be present in milk in sufficiently large quantities to endanger health. Baum, as reported by Allen (*16, p. 973*), corroborates these findings and adds phenol, morphine, belladonna, and strychnine to the list of drugs that may be transmitted in milk. Denis, Sisson, and Aldrich (*272*) report an unmistakable increase in the chlorine concentration of the milk of goats receiving calcium chloride, and Kolda (*642*) concludes that minute quantities of practically all medicinal substances administered to lactating females pass into the milk.

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[3] This section was prepared by C. J. Babcock, Market-Milk Specialist, Division of Market-Milk Investigations, Bureau of Dairy Industry.

UTILIZATION OF FEED ENERGY AND FEED PROTEIN IN MILK SECRETION

by C. A. Cary[1]

THIS technical article on two of the most important aspects of dairy cattle feeding will be of interest to dairymen who wish to understand or like to study the fundamentals of their profession. In a closely reasoned analysis, the author gives the background of experimental procedures, describes the results of a wealth of experiments, and compares them carefully from the standpoint of their bearing on practical feeding standards.

FEED ENERGY AND FEEDING STANDARDS

IT MIGHT be well before considering the bearing of utilization of feed energy on milk secretion to define certain terms. The energy requirements of cattle in this country are now very generally expressed as pounds of total digestible nutrients that will supply the energy for the function or functions in question. The total digestible nutrients in a feed are calculated by adding together all of the digestible organic nutrients—the weight of the carbohydrate, the fat multiplied by 2.25, and the protein. According to this system a pound of total digestible nutrients is the unit used in expressing the energy requirements of cattle and the energy value of feeds. The proportion of total digestible nutrients in 100 pounds of the same feed or even of the same sample of feed is not constant under all feeding conditions. For instance, the digestibility of the dry matter in rations of full-fed milking cows is less than that of the same feeds with animals that are not so heavily fed, the difference in digestibility amounting to 5 to 10 percent of the dry matter in the feed. This has been noted by a number of workers.

A pound of total digestible nutrients is often taken as equivalent to 1,814 calories (or 1.814 therms, a therm being 1,000 calories) of digestible energy; or, according to Forbes and Kriss (*375*),[2] it is equivalent on an average, with the ordinary grain-hay rations of cattle, to approximately 1,616 calories (1.616 therms) of metabolizable energy, that is, energy obtainable from it by metabolism in the organism. The pound of total digestible nutrients in cow rations, therefore, may be taken to represent on an average 1,616 calories (1.616 therms) of metabolizable energy.

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[2] Italic numbers in parentheses refer to Literature Cited, p. 1075.

The efficiency with which this metabolizable energy is utilized varies in different bodily functions and with various conditions. In considering the utilization of energy in milk secretion, the gross efficiency of utilization must be differentiated from the physiological or net efficiency. The first is the total gross energy in the milk, expressed as a percentage of the digestible energy in the total feed intake. The physiological, or net, efficiency of utilization is more complicated. It is the total gross energy in the milk expressed as a percentage of either the digestible or the metabolizable energy in that portion of the feed available for milk production after allowing for (1) the energy required for the maintenance of the animal, (2) the energy involved in any change of body weight, and (3) the energy used in gestation, if the animal is pregnant.

This article will consider the physiological or net efficiency of the utilization of energy in milk secretion, as it is upon this that the separate allowances of feed energy for milk production in the various feeding standards are based.

The percentage of the metabolizable energy available for milk production that is actually recovered in the milk—or in other words utilized in milk secretion—is not constant. According to Gaines (*405*) it may vary with the breed of the cow; according to Kellner and Armsby (*32*) and to the experimental work of Eckles (*291*), it may vary with the composition of the milk secreted; and according to calculations by Brody and Cunningham (*154*), it varies with the stage of lactation and the level of feeding. In addition, it must be borne in mind that the efficiency of the utilization of energy in a ration is affected by the completeness and balance of the ration. Rations deficient in any one essential nutrient lead to waste in the utilization of energy.

Besides these many variable factors actually affecting the efficiency of the utilization of energy in milk secretion, uncertain and arbitrary assumptions are made in arriving at expressions of this efficiency. It is true that to reduce certain errors to a minimum studies of this sort are generally carried out with cows that are not with calf, and that in ordinary feeding experiments the cows are so fed over long periods that practically no net gain or loss in body weight occurs during the period of the experiment. Sometimes also it is true that the energy maintenance requirements used in determining the energy available for milk secretion are determined for the same animals under the same conditions while milking and while not milking. More often, however, the energy allowance for maintenance is an arbitrary figure determined with a few oxen or a few entirely different dry animals, or calculated with certain assumptions regarding the relation between it and the weight of the animal, or possibly determined in a respiration calorimeter under conditions quite different from those that prevail in practice.

USE OF LONG-TIME FEEDING EXPERIMENTS IN THE STUDY OF THE UTILIZATION OF ENERGY IN MILK SECRETION

One of the most extensive series of experiments, which has contributed greatly to knowledge of the utilization of feed in milk production and has influenced feed practices in this country, was carried out by Haecker at the University of Minnesota. He was the first to set up feeding standards that varied with the composition of the milk. In summing up his work on the feed required for the maintenance of cattle he said (*453*):

> The experiments justify the conclusion that with cows at rest in stalls in comfortable quarters, a ration of 11.5 pounds of dry matter containing of digestible matter, .06 of a pound of protein, .6 of a pound of carbohydrates, and .01 of a pound of ether extract [fat] per hundred [pounds] weight of cow, will be ample for a maintenance ration.

This is equivalent to 6.8 pounds of total digestible nutrients per 1,000 pounds of weight of the animal. It was determined with barren cows kept practically at constant weight, and was calculated on the assumption that their requirements vary directly with their weight. Haecker further says—

> it is tentatively suggested for a cow working in the dairy and having ordinarily good care and comfortable quarters the allowance for maintenance be calculated at 1.25 pounds of dry matter, containing .07 of a pound of protein, .7 of a pound of carbohydrates and .01 of a pound of ether extract per 100 pounds of live weight.

This is equivalent to 7.92 pounds of total digestible nutrients daily per 1,000 pounds of weight of the animal. Haecker retained this recommendation in his final feeding standard (*455*).[3]

Using this recommended maintenance figure of 7.92 pounds of total digestible nutrients daily with milking cows so fed that they did not change materially in weight during the experiments, Haecker calculated (*455*), in summing up the results of experiments extending over nine winters, the average additional feed required for milk production. The digestible energy required, according to these data, was 1.72 times the total gross energy in the milk. This would mean that the energy in the milk is about 58 percent of the digestible energy available for its production. The averages for different years vary in these experiments from as high as nearly 69 percent to as low as 53 percent. The average figure here can be considered as only a rough approximation of the percentage utilization of feed energy in milk production, (1) because the allowance for maintenance used in the calculation was not that actually determined with Haecker's barren cows, and (2) because the digestibility of the feed was not determined by digestion trials with the milking animals but was arrived at from average figures. These discrepancies, however, tend to offset each other to some extent; and everything considered, it is quite likely that the average utilization of the digestible energy available for production in these experiments is not far from 56 to 61 percent, or approximately 63 to 68 percent of the metabolizable energy. The energy allowances for milk production according to Haecker's feeding standard are about 1.85 times the total energy in the milk, provided average total digestible nutrient values for the feeds are used; but this would actually provide digestible energy only about 1.76 times the milk energy if 5 percent is deducted from the average feed values to cover the reduced digestibility with full-fed milking animals.

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[3] The recommendation has been followed in the Savage (*1011*) standard, and Morrison (*819*) "recommended [it] for good cows under usual conditions," except that Morrison varies this maintenance energy allowance with the 0.87 power of the animal weight instead of directly with the weight as did Haecker and Savage. When this allowance for maintenance is used with tables expressing the average total digestible nutrients in feeds, it really supplies not over 7.3 to 7.5 pounds of total digestible nutrients a day per 1,000 pounds of live weight with full-fed milking cows.

The Savage (*1011*) energy allowance for milk production is not significantly different from that of Haecker, being about 1.5 percent higher.

Eckles (*291*) worked on the utilization of feed in milk production at the University of Missouri. In a well known and very well conducted experiment, he determined the feed required to maintain cows while they were dry by so regulating their diet that the net gain or loss in body weight for the experimental period was negligible. He also fed cows in like manner during a lactation period, and determined the digestibility of the feeds under both conditions. When dry, the animals required the equivalent of 6.82 to 8.56—average 7.5—pounds of total digestible nutrients per 1,000 pounds of live weight to maintain them; and Armsby (*32, p. 496*), using these actual maintenance figures and Eckles' actual digestibility figures, has calculated that 50.35 to 72.82—average 61.94—percent of the metabolizable energy available for milk secretion was actually recovered in the total energy of the milk secreted. This is equivalent to an average of approximately 55.2 percent of the digestible energy.

Both the Haecker results for the utilization of energy in milk secretion, as compared for different winter-feeding periods, and those of Eckles for individual cows show a great variation; and there is always considerable unavoidable error in any such experiments, the magnitude of which it is difficult to estimate. But if we assume here that these experimental differences represent real differences in the performances of the experimental animals, it is obvious that, in using feeding recommendations based on the averages so obtained, much is left to the judgment and experience of the practical feeder, however useful the recommendations may be as a guide to him or however carefully and painstakingly the experiments on which they are based were conducted.

USE OF MATHEMATICAL PARTITION PROCEDURE IN STUDY OF THE UTILIZATION OF ENERGY IN MILK SECRETION

Brody, also at the University of Missouri, has more recently applied a mathematical procedure to arrive at the proportion of the total digestible nutrients in the feed used for (1) maintenance, (2) change of body weight, and (3) milk production. He applied his method to groups of cattle for which records had been kept of the total feed consumption, the milk yield, and the body weight. With one group of 243 cows he calculated (*156*) that it required 8.2 pounds of total digestible nutrients per 1,000 pounds of live weight daily to supply the energy for maintenance, and that the total energy in the milk was about 61 or 62 percent of the digestible energy available for its production. This is about 68 percent of the available metabolizable energy. In two other calculations—one with 73 cows and another with 10 cows—Brody (*154*) arrived at a utilization of 51.5 and 64.5 percent, respectively, of the digestible energy, or 57.8 and 72.4 percent of the metabolizable energy available for milk secretion.

Brody (*154*) also calculated the utilization of energy in milk production at different stages of lactation for the same cows. For 12 successive 28-day periods the utilization of available digestible energy was 82, 72, 67, 62, 60, 62, 64, 63, 62, 61, 43, and 58 percent. According to these data, milk is apparently secreted more efficiently early in lactation when the impulse to secrete it is most intense and the animals are most likely to be underfed. Brody further essayed to estimate the variation in the efficiency of the utilization of feed energy at various levels of feeding. He concluded that, as would be expected, this followed the law of diminishing returns—that is, the efficiency of the utilization of energy in milk production decreases with successive increases in the amount of food; but it must be definitely borne in mind that increases that physiologically may be used less efficiently in the production of milk may nevertheless lead to increases in milk yield that are actually economically profitable.

As a result of this work Brody suggested feeding a 1,000-pound milking cow 8.2 pounds of total digestible nutrients daily to supply the energy required for maintenance. In addition he assumed that this maintenance requirement varies with the 0.73 power of the body weight of the animal, because it had been found that in general the energy loss in the basal metabolism of animals varies in this way with the body weight, and because a large portion of the energy expenditure in maintenance under practical conditions is involved in covering this loss. He calculated the energy required for milk production so that the gross energy in the milk was 61 to 62 percent of the digestible energy or about 68 percent of the metabolizable energy allowed for its production. He also used 340 calories per pound of 4-percent milk and Overman and Gaines' formula (*887*) (p. 643) to calculate the energy contents of milk containing more or less than 4 percent of fat.

It should be said, in connection with Brody's calculations, that probably not all the factors that determine practically the energy requirements of cattle vary as the 0.73 power of the body weight, and that a variation in this assumption might considerably alter the calculation of the utilization of energy in milk secretion.

CALORIMETRIC STUDIES

Undoubtedly the most meticulous work that has been done on the utilization of energy in milk production is that carried out by means of the respiration calorimeter, in which the energy intake and output of the animals have been measured as completely as possible. Kellner first carried out experiments of this sort with three milking cows. He calculated their maintenance requirements from similar experiments with oxen; and Armsby, using Kellner's data and allowing for the bodily retention or loss of energy, arrived at the metabolizable energy available for milk secretion. With these three cows, Armsby (*32, p. 495*) calculated that 68.41, 72.80, and 66.91 percent (average, 69.4) of this metabolizable energy was utilized in milk production, that is, was recovered in the milk. In a similar experiment with 11 cows at the Pennsylvania Institute of Animal Nutrition, Forbes and Kriss (*375*) obtained results varying from 64.2 to 75.8 percent (average, 69.3). This result would correspond to about 62 percent of the digestible energy. With these data and Armsby's calculations of the energy content of the milks analyzed by Haecker (p. 643), Forbes and

Kriss arrived at the energy allowances in their feeding standard for milk production. They had also found that in the calorimeter it required 5.551 pounds of total digestible nutrients daily per 1,000 pounds of live weight to maintain a cow. They thought this figure might be too low for practical purposes; and, assuming that milk would be secreted with the same efficiency under practical conditions as in the calorimeter, they used the above figures for the utilization of energy in milk production to calculate the maintenance energy requirements of cows under practical conditions. They concluded that 5.972 pounds of total digestible nutrients daily per 1,000 pounds of live weight would meet this requirement.

In closing these citations of experimental data on the utilization of energy in milk secretion, the fundamental work of Armsby with the calorimeter at the Pennsylvania Institute of Animal Nutrition cannot be passed by. When he published his book on the Nutrition of Farm Animals in 1917 (*32*), the only calorimetric results on the utilization of energy in milk secretion available were those of Kellner, cited above. Both Kellner and Armsby observed that, if it is assumed that there is no energy loss in the making of the lactose and protein in the milk but that there is an energy loss in the making of milk fat similar to the loss in making body fat from carbohydrate in the feed, the efficiency of the utilization of metabolizable energy in milk secretion would vary with the composition of the milk but would be very similar to that obtained experimentally by Kellner. Armsby set up a feeding standard for milk production based on this assumption. In his calculations he used Haecker's data on the composition of milk (p. 643). He also set up an energy standard for maintenance, which, according to Kriss (*649*), was equivalent to 6.456 pounds of total digestible nutrients daily per 1,000 pounds of animal weight.

RELATION OF ENERGY FEEDING STANDARDS TO EXPERIMENTAL DATA

In the twentieth edition of Feeds and Feeding (*819, p. 1004*), besides allowing 7.92 pounds of total digestible nutrients daily per 1,000 pounds of body weight for maintenance and varying this allowance as already stated, Morrison makes recommendations for feeding for milk production by "good cows under usual conditions." In calculating this allowance he apparently uses about 341 calories for the total energy content of 4-percent milk, calculates the energy content of other milks according to Overman and Gaines' method, and uses an efficiency of utilization of about 61 percent of the digestible energy. To this figure he adds 5 percent to offset the lower total digestible nutrient value of feeds with full-fed milking cows as compared with the average values as given in the tables in his book.

The results on the physiological utilization of energy in milk secretion and the feed allowances based on them given in this article are summed up in tables 1, 2, and 3. Data from foreign standards of feeding are inserted in table 2 for comparison. These data are given here because they are used in calculating the efficiency of the utilization of energy in milk secretion. (See table by Kriss (*649*), from which most of these data are taken.) It is obvious that the average physiological utilization of digestible energy in milk secretion is close to 60 percent, or that of metabolizable energy about 67 to 69 percent.

It is also obvious that the energy allowances for milk production according to the various standards, with the exception of Haecker's, are identical with the average calculated requirement according to the efficiency of utilization found. Whether the conditions under which these different figures were obtained reflect the most profitable practice in feeding remains to be seen.

TABLE 1.—*Percentage utilization of energy in milk secretion*

Experimenter	Energy in milk as percentage of—		Experimenter	Energy in milk as percentage of—	
	Available[1] digestible energy	Available[1] metabolizable energy		Available[1] digestible energy	Available[1] metabolizable energy
	Percent	*Percent*		*Percent*	*Percent*
Haecker	58 (53-69)	65	Kellner	62	69.4 (68.41, 72.80, 66.91)
Eckles	55	62 (50.35 to 72.82)			
Brody[2]	61, 51.5, 64.5	68, 57.8, 72.4	Forbes and Kriss	62	69.3 (64.2 to 75.8)

[1] That is, the energy available for production after allowing for maintenance and change in body weight.
[2] For groups of animals irrespective of stage of lactation.

TABLE 2.—*Energy requirements found experimentally or given in various standards for the maintenance of dairy cattle*

Author	Total digestible nutrients recommended, or found experimentally, to supply daily energy requirements for a 1,000-pound cow	Remarks
	Pounds	
Haecker	[1] 7. 925	To be used with tables of average digestibility. Probably actually equivalent to 7.3 to 7.5 pounds of total digestible nutrients.
Eckles	[2] 7. 5	Using actual digestibility.
Savage	[3] 7. 925	Equivalent actually to about 7.5 pounds of total digestible nutrients as taken from tables based on average digestibility.
Morrison	[4] 7. 925	Equivalent actually to about 7.5 pounds of total digestible nutrients.
Brody	[5] 8. 2	
Armsby	[6] [7] 6. 456	
Forbes and Kriss	[8] 5. 972	
Kellner	[6] 6. 673	
Mollgaard	[6] 5. 860	
Nils Hansson	[6] 5. 638	

[1] Average of actual determinations, 6.8. Maintenance taken as varying with the first power of the weight.
[2] Found experimentally 6.8 to 8.6 pounds; 7.5 calculated using either the first power or the two-thirds power of the weight; 6.8 to 8.6 apply only to calculations based on variation of maintenance with two-thirds power of the weight.
[3] Used Haecker's recommendation. Maintenance taken as varying with the first power of the weight.
[4] Used Haecker's recommendation. Varied as the 0.87 power of the live weight.
[5] Used the calculated result with the one group of 243 cows. Varied as the 0.73 power of the live weight.
[6] As expressed in TDN (total digestible nutrients) according to Kriss (*649*).
[7] Armsby varied the maintenance allowance of energy with the two-thirds power of the weight.
[8] Average for requirements determined under "practical" conditions.

TABLE 3.—*Energy required for milk production according to various standards, expressed in TDN [1] allowed per pound of milk*

Fat in milk (percent)	Haecker [2] [3]	Armsby [2] [3]	Forbes and Kriss [3]	Brody	Morrison [2] [4]	Mollgaard	Hansson
	Pound	*Pound*	*Pound*	*Pound*	*Pound*	*Pound*	*Pound*
3	0.284	0.230	0.251		0.261 or 0.276	0.252	0.267
4	.343	.285	.300	0.305	.307 or .324	.302	.302
5	.398	.339	.350		.353 or .373	.351	.339
6	.451	.388	.393		.399 or .422	.396	
7	.502	.439	.433		.445 or .470	.437	
4 [5]	.331	.275	.3045	.305	.293 or .309		
	Percent	*Percent*	*Percent*	*Percent*	*Percent*		
Energy in milk in percent of available digestible energy [6]	56.8	68.3	61.7	61.6	64.1 or 60.8		
Energy in milk in percent of available metabolizable energy [6]	63.7	76.6	69.3	69.1	71.9 or 68.2		

[1] TDN stands for total digestible nutrients.

[2] Calculated to be used with tables giving average total digestible nutrients in feeds without further allowance for the lower digestibility in case of milking animals.

[3] Based on the energy content of milk calculated by Armsby from Haecker's analyses (table 5, p. 643).

[4] Based on 4-percent milk with an energy content of about 340 calories per pound, using Gaines' formula to calculate the energy content of milks with different other percentages of fat.

[5] Actual total digestible nutrients allowed for 4-percent milk containing 341 calories per pound, using the same percentage utilization of energy in each case as in the figures above.

[6] Calculated from the actual TDN allowed, and the energy content of milk (footnote 5).

UTILIZATION OF PROTEIN IN MILK SECRETION

Before considering the results of experimental work on the conversion of feed proteins into milk proteins, it may be well to recall four fundamental facts that, although fully recognized by all workers in this field, are frequently obscured by the conventional methods of expressing results.

(1) In analyzing feeds, the amount of nitrogen they contain in chemical combination is multiplied by a certain factor—generally 6.25—and the figure thus arrived at is taken as the protein content of the feeds. The factor varies somewhat, depending on the percentage of nitrogen in the particular feed proteins considered.

(2) When the digestibility of a feed protein is given as 60 percent, it means that the chemically combined nitrogen in the feces of the animal is 40 percent as much as that in the feed. It does not mean that 40 percent of the feed protein has passed unchanged into the feces, for a large amount of nitrogen is excreted in the feces on a diet entirely devoid of protein. Much of the nitrogen in the feces occurs in unabsorbed gastrointestinal secretions and debris, and in bacterial products formed from various nitrogenous materials. The amounts of this so-called metabolic fecal nitrogen on a diet without any protein vary with the quantity of feed and particularly with the quantity of indigestible material in the feed. The increase in the excretion of nitrogen in the feces as a result of adding protein to the diet frequently accounts for only a small fraction of the added feed protein. To use an extreme illustration, the digestibility of the protein in straw is ordinarily given as about 30 percent; but after allowing for the metabolic nitrogen that may occur in the feces on such a diet, even if it contained no protein, it has been calculated that the increase in fecal nitrogen due to the protein in the straw is negligible, accounting possibly for not over 10 percent of the protein in the straw; and it might with

reason be questioned whether or not this small amount of straw protein actually passes chemically unchanged into the feces. When 50 to 60 percent of a feed protein is said to be digestible, it is possible that actually 90 to 100 percent of it is digested; 90 to 100 percent of the amino acids are actually absorbed and are available for the various bodily functions, including the formation of the materials ultimately excreted as metabolic fecal products, other maintenance processes, and milk secretion.

(3) As pointed out elsewhere in this Yearbook (pp. 177, 439), it is now known that only 9 of the 20 or more amino acids formed in the digestion of various proteins need be supplied in the diet of the rat to produce some growth; and, according to a recent paper (*226*), these amino acids are required for maintenance alone. For normal growth another amino acid, arginine, which is made by the rat at a sufficient rate to permit some growth or for maintenance alone, must be supplied to some extent in the diet. No such extensive work has been carried out on the amino acid requirements of other animals; and little is known either qualitatively or quantitatively about the amino acids that must be supplied in the diet for any function or combination of functions. So far as is known, no amino acid that has been found essential in the diet of the rat is synthesized by other animals, but knowledge at present is very meager in this matter.

On one important question there is a complete lack of knowledge: Can all of the amino acids not found to be essential in the diet of the rat for growth and maintenance be synthesized for milk secretion readily enough so that a lack of them will never impede or limit the production of milk; or is it advantageous to supply these amino acids "ready made" in the diet of lactating animals? The amino acids that it is essential to supply in the diet of the rat constitute about 40 percent of the weight of the proteins in cow's milk; those which the rat apparently can synthesize constitute 60 percent of the milk proteins. Whether the particular amino acids that constitute only 40 percent of the weight of the milk protein are the only ones that must be supplied for milk production cannot now be said; nor can it be said what raw materials may be required for the synthesis of the amino acids that constitute the other 60 percent of the milk protein, or whether it may promote milk production to supply these other amino acids also. The possibility of the synthesis of amino acids by bacteria in the paunch of ruminants must also be kept in mind; for there is definite evidence indicating—or so it is interpreted—that these animals may use simple nitrogenous compounds such as urea in place of protein.

(4) An additional fact must be considered in connection with the utilization of protein in milk secretion. The amino acid make-up of the milk proteins, particularly casein, is known, both qualitatively and quantitatively, to a considerable extent. This is not true of the amino acid make-up of the mixtures of proteins in feeds, or the amino acids required for maintenance or excreted in metabolic fecal nitrogenous materials. It is quite likely that some amino acids required in relatively large quantities in the synthesis of milk proteins may be needed in relatively very much smaller quantities in such bodily processes as are involved in the maintenance of the

animal. In such cases, amino acids in the feed quota allowed for maintenance supplement deficiencies of amino acids in the protein allowed for production; and the total dietary protein is thus used much more efficiently than would be anticipated were it possible to determine its utilization separately for each of these functions. That this is most likely an important factor in determining the utilization of feed protein in milk production will appear later.

The method of expressing protein requirements separately for maintenance and milk production does not mean that the dietary quotas allowed for these functions are used separately and independently in the body of the animal to serve these functions. It simply means that the amount of protein allowed for maintenance is considered adequate for the nonlactating animal, and that when the animal is milking a certain amount more is needed to meet the processes of maintenance and milk secretion together. The method of expressing protein requirements certainly should in no way lead to the assumption that the protein metabolism of the milking animal is the same as that of the nonlactating animal plus simply the added operations going on in the mammary gland. The lactating animal should rather be considered as a whole—as a new manufacturing plant or a new organization temporarily operating as a new unit under new management. Probably the endocrine set-up and organization of the lactating animal is temporarily altered as this analogy would suggest. Any calculation of the utilization of protein in milk production that disregards this situation may lead to entirely erroneous and incredible results.

CALCULATION OF THE POSSIBLE UTILIZATION OF FEED PROTEINS FROM KNOWLEDGE OF THEIR AMINO ACID COMPOSITION

It is true that there are very few reliable data on the amino acid composition of the protein mixtures in feeds that under any circumstances would enable the calculation, from their chemical composition, of their possible use in the synthesis of milk proteins. Morris and Wright (*817*), at the Hannah Research Institute in Dairying in Scotland, noted that frequently the utilization of a feed protein, added for milk production to a certain basal feed mixture, seemed to vary with the lysine content of the added protein. These workers determined the lysine content of a large number of feed proteins. The data are shown below, averaged with similar figures quoted by Morris (*816*) from other workers. The figures undoubtedly are not accurate, but they may be roughly comparable. At any rate they will illustrate how the amino acid composition of a feed protein may affect its utilization in milk production.

	Lysine nitrogen (percent)		*Lysine nitrogen (percent)*		*Lysine nitrogen (percent)*
Skim milk	8. 27	Peanut cake	4. 46	Red clover hay	2. 62
Blood meal	10. 38	Alfalfa	4. 43	Wheat	2. 47
Meat meal	8. 14	Wheat bran	4. 15	Corn	2. 17
Beans	7. 44	Cottonseed meal	4. 21	Barley	2. 19
Peas	7. 04	Linseed meal	3. 51	Oat straw	1. 29
Soybeans	6. 18	Oats	2. 91	Beet pulp	. 23

On the assumption that the lysine for the production of milk proteins must be supplied in the feed, it is obvious from these data that 1 pound of blood-meal protein or meat-meal protein could supply enough lysine to make 1 pound of milk protein, and also that this is not quite true for any vegetable protein in the list. With the proteins in beans, soybeans, and peas it would require only 11 to 34 percent more protein in the diet than is secreted in the milk; with the proteins in peanut cake, wheat bran, cottonseed meal, and linseed meal it would require at least twice as much; but with the other feed proteins listed it would require at least three or more times as much feed protein as there is in the milk for its production. Although it might be worth while to repeat the analyses with recent improvements in procedure, Wright and his collaborators have in a number of instances obtained effects on milk yield in accord with these data. In applying these conclusions, it should be remembered that the lysine for the synthesis of milk protein need not come entirely from the protein supposedly furnished for production requirements. Morris and Wright (*818*) have roughly estimated that only about 4 grams of lysine are required for the maintenance of a 1,000-pound cow, and anything over this amount in the maintenance allowance might be used for milk production.

USE OF BIOLOGICAL VALUES IN CALCULATING PROTEIN REQUIREMENTS FOR MILK SECRETION

Mitchell (*795*) has approached the problem of the protein requirements for milk production from another viewpoint. The "biological value" of a protein for a single function like milk production cannot, of course, be determined; but he suggests that the biological value of proteins in covering the various functions in milking ruminants may safely be assumed to be not less than 50 percent, and that the dietary protein requirements of these animals may be roughly approximated accordingly. He would thus feed an amount of digestible protein equivalent to twice the protein secreted in the milk to cover the protein requirements for its production.

BALANCE EXPERIMENTS ON THE UTILIZATION OF PROTEINS IN MILK SECRETION

A third method used in the study of the utilization of proteins by milking animals is one in which account is kept of the total nitrogen intake and output of the animal. The method is also used to determine whether or not a milking animal is receiving a ration to which it is possible for her to adjust herself. Very great care must be exercised in conducting and interpreting such experiments. For instance, in studying the utilization of feed protein in maintenance and milk production, the animal should be approximately in nitrogen equilibrium (p. 181) or else the utilization of the amino acids in the feed mixture will be altered by those derived from the body tissues or being used in the synthesis of tissue. However, in studying the possibility of an animal's accommodating itself eventually to a given feeding regime, a positive or negative nitrogen balance may simply mean that the period allowed for adjustment has been insufficient. Even apparent equilibrium between the intake and output of nitrogen in such experiments is not an abolute guarantee of actual balance and adjustment of the animal to the given feeding regime, for the amount the animal is out of balance may be within the limit of the experimental error of the procedure used.

Such difficulties in the conduct and interpretation of balance experiments are generally recognized and may be illustrated by the well-known experiments of Hart and Humphrey (*486*) on the relation of the quality of protein to milk production. These experiments demonstrate clearly and strikingly a difference in the utilization of feed proteins in milk production. The milk yields were not much affected by the changes in the kind of protein in the diet; but when milk proteins were fed along with a basal ration of corn stover and a small amount of starch, the cows laid on protein reserves in their bodies; whereas, when the same quantities of wheat or corn proteins were fed with the same basal ration, the cows actually "milked flesh off their bodies" in obtaining protein to keep up this milk yield. It is impossible to assign numerical values that will express this striking difference in the value of these feed proteins, for when the milk proteins were fed the figures would include their use in tissue synthesis as well as maintenance and production, whereas with the wheat and corn proteins the figures would include the tissue proteins that supplemented them in maintenance processes and production. Nevertheless the results of these experiments, besides clearly demonstrating a difference in the value of feed protein, demonstrate also that the amino acid mixtures available for production on the various rations were used with a very high degree of efficiency. If it is assumed that the nitrogen absorbed with the milk proteins in the diet was used with 100-percent efficiency in the synthesis of milk and new tissue proteins(which would not be true), then the equivalent of only 0.4 pound daily of absorbed protein was available per 1,000 pounds of live weight to cover the requirements for the maintenance processes going on in these animals. With the corn or wheat proteins in the diet, this figure on the same basis was about 0.6 or 0.7 pound per 1,000 pounds of live weight, respectively, using average weights for animals of the breeds used. This economy of utilization of protein on the corn and wheat diets was obtained under conditions which, of course, could not continue in practice. The nitrogen in the milk protein produced in this experiment was from 20 to 35 percent of the total nitrogen in the feed minus that equivalent to the nitrogen in the protein laid on in the tissues or plus that lost from tissues when the nitrogen balance was negative.

In two other papers, Hart and Humphrey (*487*, *488*) compare the same series of proteins when fed to milking cows to supplement different basal rations. When fed along with corn stover and corn silage, the proteins in gluten feed were found to be inferior to those in oil meal, distillers' grains, casein, or skim-milk powder; but the proteins in gluten feed, oil meal, distillers' grains, and cottonseed meal were equally efficient as supplements to a basal ration of corn meal, corn silage, and clover hay.

These workers also found that—

> it is not possible to furnish dairy cows of high milk-producing capacity with a protein level of sufficient magnitude or quality to maintain that capacity from a clover-corn silage-cereal grain mixture, the latter being corn, barley or oats alone or a mixture of the three (*489*);

but that this is possible when alfalfa is substituted for the clover.

Armsby (*32, p. 491*) has calculated the percentage utilization of protein in milk production from balance experiments similar to those of Hart and Humphrey. The experiments were carried out by Jordan, Hayward, and Kellner (see Armsby (*32*)) and in the Laboratory for Experimental Research in Copenhagen. The animals in all of the experiments were on low-protein rations; most of them were losing more or less nitrogen from their bodies. Armsby in his calculation allowed 0.6 pound of digestible protein daily to cover the requirements for maintenance. If, in order to arrive at the protein available for production, the nitrogen laid on by the animal in new tissue is subtracted from the absorbed nitrogen, or the nitrogen lost from the tissues is added to it, the average occurring in the milk would be 116, 93, 91, and 96 percent, respectively, of the available nitrogen in these experiments. As most of the animals were apparently losing some nitrogen from their bodies, this efficiency of utilization, like that of Hart and Humphrey, could not obtain in practice or be used with assurance in calculating the protein to be added to the assumed maintenance allowance to cover the requirements for milk secretion. It would also be difficult to estimate the adjustment in feed protein necessary to bring these animals into nitrogen equilibrium or to tell whether in the course of time such an equilibrium would occur without change of diet or without reduction of milk yield.

In considering the maintenance allowance used by Armsby in these calculations, it should be pointed out that in several such studies nitrogen equilibriums or positive nitrogen balances have been reported under conditions where, if 0.6 or 0.7 pound of digestible protein daily per 1,000 pounds of animal weight be allowed for maintenance, more protein would have occurred in the milk than the amount of digestible protein left for its production, as in the experiments of Jordan and as with the cows of Hart and Humphrey when on the milk protein rations. This means that the nitrogen used in maintenance in the milking animal is less than that calculated; but it does not mean that this nitrogen used in maintenance (or the amino acids it represents) is necessarily different in milking and dry animals, for in either instance the amino acids actually used in maintenance are only a select portion of the total feed protein required to supply them.

Forbes and Swift (*376*), at the Pennsylvania Institute of Animal Nutrition, have presented data on the efficiency of the utilization of protein in milk production in a paper based on 45 nitrogen balances determined with milking cows. The average milk yield was 42.6 pounds daily; the cows were fed "all that they could be depended upon to clean up absolutely without waste," which "signifies that they were not up to full feed"; and "the proportion of protein in the rations was considered to be liberal." The average nitrogen retention for all 45 balances was 8.1 grams daily, 24 of the balances being positive and 19 negative. If 0.6 pound of digestible protein be allowed for maintenance, about 80 percent of the digestible protein was used in maintenance and in the synthesis of milk and tissue proteins. This experiment, recalculated, shows that a positive nitrogen balance and a good average yield of milk may occur on a level of digestible protein equivalent to 0.65 pound daily per 1,000 pounds of live weight plus

1.5 times the protein in the milk, which is practically what was fed on an average in these experiments, and which is the allowance now "recommended for good cows under usual conditions" in Morrison's Feeds and Feeding (*819, p. 1004*).

The data are of practical importance as indicating the efficiency with which protein can be used by milking cows when fed at a level that has been recommended as optimum for practical use. The data in themselves, however, do not bear on the question of whether the level of feeding was optimum or not. The average positive nitrogen balance was undoubtedly due only to some temporary condition, possibly in part to the method used to get the animals promptly onto their experimental rations. Nitrogen equilibrium is possible at various levels of protein feeding. An imbalance within the range at which equilibrium may come about simply means that the experimental animals have not yet completed their adjustment to the current conditions, and not that the feed allowance is too much or too little. Nitrogen equilibrium may occur at an even higher level of feeding than was used here; the protein may be physiologically less efficiently used; but whether the increased feeding would be profitable or not would depend upon the capacity of the animal to respond with increased production to these increments in feeding.

LONG-TIME FEEDING EXPERIMENTS WITH VARIOUS LEVELS OF PROTEIN IN THE DIET

The results of the balance experiments of Hart and Humphrey, of Forbes and Swift, and of those taken from Armsby should be considered in connection with those obtained in practical feeding experiments of long duration carried out to obtain the minimum level of feed protein necessary for milk production. The work most often mentioned in this connection is that of Buschmann in Germany (*176*), Hills at Vermont (*515*), and Perkins at the Ohio Agricultural Experiment Station (*907*). The last will be considered here, because Perkins' experiments took complete account of the feed intake and some with individual cows were of very long duration. For instance, Perkins (*908*) presents data for a cow that for five full lactation periods produced on an average the equivalent of 6,037 pounds of 4-percent milk on a ration that would supply 0.55 pound of digestible protein daily for maintenance provided an amount of protein only equivalent to that in the milk were allowed for production. Perkins does not regard this as a practical ration but says: "Several investigations reported in the last ten years have shown that satisfactory results may be expected from the use of a ration supplying approximately 1.25 pounds of digestible crude protein per pound of protein contained in the milk, in addition to the customary maintenance allowance" of about 0.7 pound of protein per 1,000 pounds of live weight.

In his papers Perkins recognizes that additional protein may be desirable from a commercial standpoint; and he is quoted (Kriss (*649*)) as saying that optimum production occurs at levels of protein feeding equivalent to between three and six times the protein in the milk secreted, besides the allowance of 0.7 pound daily of digestible protein for maintenance.

Perkins presents balance-experiment data with some of his cows. With one fed somewhat below what he recommends in practice (*910*) the ration contained 1,230 grams of total protein, and the cow made 359 grams of milk protein—a result not at all inconsistent with what is known (and not known) of the chemical make-up of feed and milk proteins and of the amino acids involved in maintenance and the production of the metabolic fecal materials. If with this cow 1.25 times the protein in the milk were allowed for milk production, about 244 grams (or 0.54 pound) of digestible protein would be available for maintenance. Such economy of the utilization of protein in milk production must be recognized as possible. Two questions, however, arise: (1) How generally does such economy prevail in practice, and (2) is this the level at which it is most profitable to feed?

Tests to answer the first question have been made at the Bureau of Dairy Industry farm at Beltsville, Md. (*196*). A low-protein feeding regime similar to that used with Perkins' cow above—containing 0.5 pound of protein daily per 1,000 pounds of live weight for maintenance plus 1.25 times the protein in the milk—was compared with a ration containing 0.7 pound of protein daily per 1,000 pounds of live weight for maintenance and twice that in the milk for production.

Two Jersey cows were first put on the high-protein ration for a lactation period. Their rations contained some casein. At the end of this lactation period, this protein was replaced with a carbohydrate preparation so as to reduce the amount to that in the low-protein feeding regime. One of the cows remained on this low-protein ration for one lactation period. The yield of milk and of milk fat each dropped 50 percent as compared with the previous lactation period. At the end of this period on the low-protein ration, the cow was changed back to the high-protein ration by replacing with casein a little of the carbohydrate preparation in the ration; and in the succeeding lactation period, she returned fully to her original level of production.

The second cow in this experiment behaved quite differently in some respects. During her first lactation period on the low-protein ration she showed only a very slight drop in production. She was, therefore, continued on this ration for another lactation period. She calved normally and then failed decidedly in production, going dry within 5 months. During this second lactation period on the low-protein ration she produced only 1,898 pounds of milk and 62 of fat—less than 27 and 18 percent, respectively, of her milk and fat production on the previous high-protein ration; and the fat in her milk dropped from an average of 4.8 to an average of 3.3 percent. After this failure in lactation the second cow was put on the high-protein feeding regime, and, like the first cow, in her next lactation period she did fully as well as she had previously done.

This experiment demonstrates quite clearly the inadequacy of the low-protein feeding regime with these Jersey cows—that is, the inadequacy of feeding 0.5 pound daily of digestible protein per 1,000 pounds of live weight for maintenance plus an amount of digestible protein equivalent to 1.25 times the protein in the milk to cover the requirements for production. It also shows dramatically the effect of this particular type of deficiency with milking animals. The animals appeared normal, and reproduction occurred normally. There was a loss in body weight, but the only other observable result of this deficiency of protein in the diet was the effect on lactation. Two further facts may be noted in this experiment in connection with the second cow. (1) Hart and Humphrey showed that when a milking cow is put on a diet inadequate to supply her protein requirements, she may maintain her milk at the expense of protein taken from her own body tissue. The present experiment shows that a condition of this sort may continue for a whole lactation period on a diet on which continued production is finally impossible. (2) The difference in production between the second lactation period on the low-protein diet as compared with the first was not due to any difference in feeding but rather to a difference in the nutritional state of the animal as a result of previous feeding. This illustrates the importance of feeding in preparation for lactation.

Since feeding milking cows 0.5 pound of digestible protein daily per 1,000 pounds of animal weight, plus an amount of digestible protein equivalent to 1.25 times the protein in the milk produced, may lead to disaster with some cows, the question arises as to what might happen if the protein allowance for maintenance were somewhat increased, say to 0.7 pound daily of digestible protein per 1,000 pounds of live weight, with the allowance for production not materially altered. This level of feeding has been carefully tested out and compared with other feeding regimes in an extensive practical feeding experiment by Harrison and Savage (*484*) at the New York (Cornell) Agricultural Experiment Station. They fed a basal ration of silage and hay to three groups of milking cows. In addition, these groups of cows received while milking grain mixtures containing, respectively, 16, 20, and 24 percent of total protein, equivalent to 12.7, 16.3, and 19.5 percent of digestible crude protein. The cows were so selected that the milk yields of the three groups were initially as nearly alike as possible. The ratio of the grain allowed in the ration to the milk produced was the same in all three groups. During the first lactation period the difference in production between the three groups was small, the group receiving the 20-percent total protein ration doing slightly better than the group getting the grain mixture containing 16 percent of total protein. During the second year of the experiment the difference was slightly greater than during the first.

The authors conclude:

> A 16 percent total protein concentrate mixture with No. 2 medium timothy-clover mixed hay and corn silage as roughages will give as high production when fed at the rate of one pound of concentrates to each three and one-half pounds of milk produced as either a 20 percent or a 24 percent total protein concentrate mixture. When 0.7 of a pound of digestible protein is deducted, per 1,000 pounds live weight for maintenance, a 16 percent total protein concentrate mixture fed with mixed hay and corn silage furnishes 127.8 percent of the protein in the milk. This amount of protein proved to be adequate for efficient and economic milk production.

Again, in comparing these rations, Harrison and Savage say—

> when 0.7 pound of digestible protein per 1,000 pounds live-weight is deducted for maintenance the ratio of the digestible crude protein consumed to the protein produced in the milk, both years, was as follows: 16-percent group 127.8 percent, 20-percent group 149.8 percent, 24-percent group 180.6 percent. The 16-percent concentrate mixture furnishing 127.8 percent of the protein in the milk was just as effective in milk production as either the 149.8 percent or 180.6 percent.

One pound of hay and three pounds of silage were fed for each 100 pounds of the cow's live weight in this experiment, and most of the cows weighed between 1,200 and 1,300 pounds. A ration containing a grain mixture with 12 percent of total protein was tested out and found to be unsatisfactory.

These conclusions of Harrison and Savage cannot be quoted, however, without noting one result that might eventually be found to disturb their finality. It is in regard to the performance during the second year of the same cows that were fed these various levels of protein for 2 successive years. None of those that received the ration containing the 16-percent grain mixture produced more milk the second year on this ration than they did the first; whereas four of the nine cows on the 20-percent protein ration and seven of the nine cows on the 24-percent ration produced more milk the second year than they did the first. The average increase of the seven cows on the 24-percent protein ration for the two lactation periods was 800 pounds. In time feeding these grain mixtures richer in protein, therefore, might prove profitable. However, doubt is cast on this conclusion with some cows, at least, for despite this observation it must be recognized that Perkins' cow, previously referred to, went for 5 years on less protein than Harrison and Savage fed in the ration that contained the 16-percent grain mixture, and produced on an average the equivalent of 6,037 pounds of 4-percent milk. It is also true that positive nitrogen balances have been obtained on levels of protein feeding close to that used in Harrison and Savage's 16-percent protein ration (Perkins, and also Maynard, Miller, and Krauss (*772*)). But, in considering the significance of these, it must be borne in mind that duplicate animals when identically fed may not agree very well in the story they tell and may reverse themselves from period to period in the same experiment; and that therefore the probable error in such work may be great where the experimental periods used are few or short.

Although cows may frequently maintain their milk yields for long periods at the expense of their bodily stores of protein, as in the experiments of Hart and Humphrey and at the Bureau of Dairy Industry farm, some cows respond immediately with decided changes in milk yield and in the composition of the milk when drastic changes are made in the quantity or quality of protein in their diet. Wright and his collaborators at the Hannah Research Institute in Dairying in Scotland (*816*, *817*) have carried out a series of experiments in which they varied the quality of protein in the diet much as Hart and Humphrey did. They fed milking cows the equivalent of 0.65 pound of crude digestible protein daily per 1,000 pounds of live weight plus about 1⅓ times the amount of protein in the milk produced. The maintenance ration in Wright's experiments was kept constant in composition. The protein in the portion of the ration that was added for production was supplied from various sources. The feeding of some of these proteins was accompanied by a depression in milk yield, while others brought about a recovery or a more normally sustained yield. Apparently with this feeding regime some of the proteins were adequate and some were not adequate to maintain production.

The experiments of Harrison and Savage and of Wright and his collaborators are exceedingly important. They test out approximately the protein feeding level recommended by Perkins, which is slightly more liberal than the "minimum allowance advised" in Morrison's Feeds and Feeding (*819*).

At the conclusion of their experiments, Wright and his collaborators, using certain assumptions, calculated biological values for milk production for the proteins they used, and arranged the proteins accordingly, as follows:

Source of protein	Biological value for milk production
	Percent
Fresh and dried spring grass	75–80
Grass silage (made from summer grass)	
Low-temperature dried blood meal	
Fresh and dried autumn grass	60–65
Bean meal and pea meal	
High-temperature dried blood meal	55–60
Meat meal	
Decorticated earthnut cake	50–55
Decorticated earthnut cake and flake maize	
Linseed cake	45–50
Linseed meal	

These numerical values are purely arbitrary, and the arrangement very likely would not be found to apply if the proteins were fed in connection with a different basal ration from that used. This arrangement and the assigned values are of interest, however, as expressing qualitatively the effect and relative utilization of these proteins in milk production in the feed combination used. They are also of interest because in a number of instances Wright et al. noted a correlation between the lysine content of the protein in these feeds and the values assigned to them.

It is impossible to review here all of the experimental work on the relation of the level of protein in the feed to the production of milk. The work mentioned has been cited to show the approximate minimum level of feeding at which milk may be produced, the effect of the quality of protein upon its utilization, and finally the effect of feeding amounts of protein much in excess of the minimum necessary for production. These citations would not seem complete, however, without referring to Haecker's (*455*) work on the amount of protein to feed for milk production. For four winter feeding periods Haecker fed cows digestible crude protein equivalent to an average of 1.68 times that estimated to be in the milk produced. This was in addition to 0.7 pound per 1,000 pounds of live weight for maintenance. The milk yield of these cows was no better than that of others in a second series of four winter feeding periods where the average digestible protein was only 1.38 times that in the milk. In concluding these 8 years of experimental work Haecker said:

> It appears from these results that an allowance in the daily ration of 1.5 units of crude protein [digestible] to one unit of protein in the milk would be ample under the condition that obtained in the Station herd.

He recommended the use in practice of an amount of digestible protein equivalent to 1.75 times the protein in the milk (see p. 643 for composition of milks analyzed by Haecker). It will be recalled that Perkins is quoted as saying that the optimum production of milk occurs at levels of feeding between three and six times the protein in milk even when 0.7 pound of digestible protein daily is allowed for maintenance.

Forbes and Kriss in 1931 (*375*) set up a feeding standard in which they recommended 0.6 pound of digestible crude protein daily per 1,000 pounds of live weight for maintenance plus an amount of digestible protein equivalent to between 1.25 and 1.75 times the protein in the milk. Morrison's standard in Feeds and Feeding (*819*) is also expressed in terms of crude digestible protein. He recommends 1.25 to 1.5 times the protein in the milk plus 0.6 to 0.65 pound of protein per 1,000 pounds of live weight for maintenance. These recommendations are, of course, based on average conditions. The quality of the protein in the feeds used and the capacity of the animal to respond to various levels of feeding are factors that must be taken into consideration by the individual feeder.

Although drastic changes in the quality or quantity of proteins in the ration may affect concentrations of protein and fat in the milk, this has been negligible in cases where the milk yield was not decidedly affected.

THE VITAMINS IN MILK AND IN MILK PRODUCTION

by C. A. Cary [1]

DOES milk vary in its content of vitamins A, C, and D, and the B vitamins? How does feeding affect these variations? What are the effects of variations, in the feed or the milk, on mature animals and on suckling young? The author gives a critical summary of much of the up-to-date evidence on these questions. A good deal of technical material is included along with the general conclusions.

VITAMIN A

THE YIELD of milk is directly affected little if at all by a deficiency of vitamin A or of its precursors in the diet of the cow. Normal milk secretion may ensue even after a deficiency of vitamin A sufficient to interfere with normal calving. This is true unless the health of the cow is otherwise definitely affected or there is some definite local infection.

On the other hand, one of the most variable properties of milk is its vitamin A potency. Cow's milk may be a good source of vitamin A; but milk has been produced experimentally so low in vitamin A that nursing calves have developed night blindness. The vitamin A potency of cow's milk is due mainly to two substances that occur entirely in the milk fat—β-carotene, a yellow pigment which is the main precursor of this vitamin in cattle feeds, and colorless vitamin A itself, which the cow has made from this plant precursor. Of course when other precursors of vitamin A, such as α-carotene, occur in the feeds—as when carrots are fed—some of them occur in the milk fat; or when cod-liver oil is fed, some of the colorless vitamin A in it may pass unchanged into the milk fat. Generally, more than 90 percent of the natural color in butterfat is due to β-carotene derived directly from the feed, and the remaining color to xanthophylls, vegetable pigments that are inactive as sources of vitamin A.

Some species of animals convert carotene into vitamin A more completely than others. This alters the proportions of the vitamin A potency in the milk fat that are due to carotene (when not otherwise indicated, β-carotene is meant) or to the colorless vitamin A derived from it. This is also true with different breeds of cattle. Thus on the same diet Jerseys and Guernseys secrete a more highly colored butterfat than Holstein-Fresians, Brown Swiss, and Ayrshires; but this does not necessarily mean that butterfat from Jersey and Guernsey milk is correspondingly richer in vitamin A. In fact the data at hand (from experiments at Indiana, Ohio, Nebraska, Pennsylvania, and Wisconsin), though not in accord, tend to indicate that the total vitamin A potency of butterfat from the milk of different breeds of cows on the same diet is not decidedly different.

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The quantity of carotene in the diet of a cow is by far the most important factor affecting the color and the vitamin A potency of the butterfat in its milk (table 1). On appropriate diets, Jersey butterfat that is practically colorless and Holstein butterfat with a rich deep color may be produced. As a result of differences in the carotene content of the diet some butterfats may be 15 times as highly colored as others, and such differences in color are a rough indication of the vitamin A potency of the fat. With very large quantities of carotene in the diet, however, the vitamin A in the butterfat appears sometimes to reach a rather definite "ceiling value" (table 2). Grains are a poor source of vitamin A. Even yellow corn, the richest of the grains in precursors of this vitamin, is a poor source of them. A cow usually derives well over 90 percent of her vitamin A requirements from β-carotene in the roughages in her rations.

TABLE 1.—*Relation between the quantity of carotene in the feed and the amount of vitamin A in the milk* [1]

Lot No. and ration [2]	Carotene in the feed	Vitamin A in the milk	Lot No. and ration	Carotene in the feed	Vitamin A in the milk
	Milligrams	*International units*		*Milligrams*	*International units*
Lot 1:			Lot 2:		
Herd ration	357	6,644	Herd ration	298	5,894
A. I. V. ration	561	11,389	A. I. V. ration	510	10,785

[1] Data from Peterson, Bohstedt, Bird, and Beeson (*916*).[a]

[2] The herd ration consisted of grain, hay, and corn silage. In the A. I. V. ration, A. I. V. alfalfa silage replaced the corn silage and one-half of the hay. 2 lots of A. I. V. alfalfa silage were used. (For an explanation of A. I. V. silage, see Losses in Making Hay and Silage, p. 992.)

[a] Italic numbers in parentheses refer to Literature Cited, p. 1075.

TABLE 2.—*Relation between the carotene in the feed and the concentrations of carotene and vitamin A in the butterfat* [1]

Group of cows and ration [2]	Carotene per gram of butterfat	Vitamin A per gram of butterfat	Group of cows and ration	Carotene per gram of butterfat	Vitamin A per gram of butterfat
	Gammas	*Gammas*		*Gammas*	*Gammas*
D1, Control	0.94	2.86	D4, Ration included 70 pounds of A. I. V. grass silage plus 4 pounds dried grass	4.28	5.51
D2, Ration included 40 pounds of A. I. V. grass silage	2.95	5.53			
D3, Ration included 70 pounds of A. I. V. grass silage	3.67	4.81			

[1] Data from Gillam and Heilbron (Watson et al. (*1190*)).

[2] The A. I. V. grass silage and the dried grass added to the ration were both rich in carotene.

The effect of roughages in the diet is well shown in an experiment by the Bureau of Dairy Industry at Beltsville, Md., in which the vitamin A potency of butterfat from cows fed U. S. No. 1 alfalfa hay was compared with that from cows fed U. S. No. 3 timothy hay. The vitamin A potency of fat from the former was 4 times that of fat from the latter, though on an average U. S. No. 1 alfalfa hay contains about 8 to 10 times as much carotene as does U. S. No. 3 timothy hay. The vitamin A potency of these butterfats was determined biologically.[3]

Many cows in this country are fed a ration consisting of a grain mixture, corn silage, and hay. If a good alfalfa hay is fed, the milk may contain 1,200 to 2,500 Sherman units of vitamin A per quart (average, about 2,000 units per quart); and the butterfat may vary from 35 to 68 (average, 50) units per gram. Very good clover hay may give practically the same result; but with most of the clover hays on the market the vitamin A content would be much less. Butterfat from milk from cows fed soybean hay has been reported as containing about 35 Sherman units of vitamin A per gram. Fats from milk from cows fed timothy hay have been reported that contained as little as 8 and 13 units of vitamin A per gram. A cow fed a very good grade of timothy hay may produce a butter containing more vitamin A than this, but feeding a very poor timothy hay as the only roughage in the diet may result in a butterfat containing only about 1 Sherman unit of vitamin A per gram. Butterfat that is similarly poor in vitamin A may result also from the use of very poor alfalfa hay as the sole roughage in the diet.

In some parts of the country all-roughage rations are fed, and workers (*523*) at Puyallup, Wash., have determined the effect on the vitamin A potency of butterfat of feeding such rations. The feeding of home-grown, field-cured hay (grass), according to these workers, led to the production of butterfat containing 50 Sherman units per gram; whereas a hay and grass-silage ration, a grass-silage ration, or a ration of pasture alone led to the production of fat containing about 86, 97, and 105 Sherman units of vitamin A per gram, respectively.

The Texas Agricultural Experiment Station (*225*, *384*) has published considerable data on the vitamin A potency of butterfat produced on rations that are used to a considerable extent in the Cotton Belt. According to their data a ration consisting of cottonseed meal and cottonseed hulls led to the production of butterfat containing 2.5 Sherman units of vitamin A per gram. The addition of white corn and beet pulp did not improve this condition; and even yellow corn with beet pulp, or with beet pulp and wheat bran, had little effect, the butterfat containing only 2 to 5 units of vitamin A. Three to five pounds of alfalfa meal added to this latter ration led to a butterfat containing 7 to 11 units of vitamin A. Feeding sorghum silage along with the cottonseed meal and hulls produced a butterfat containing about 7 units of vitamin A per gram; while this ration with pasture led to a butterfat containing 33 units per gram. The effect of pasture feeding upon the vitamin A potency of butterfat depends on the condition of the pasture. The workers at the Texas station report that a gram of butterfat contains on an average about 38 Sherman units of vitamin A, their cows presumably being on pasture most of the time.

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[3] It is difficult at present to compare results of the determinations of vitamin A in milk and butterfat made in different laboratories. Most of the determinations in this country have been made by the Sherman method. Results from different laboratories expressed in growth units according to this method as it has been used are not really accurately comparable and are not accurately convertible into International Units, since a Sherman unit of growth has been reported with rats fed amounts of carotene varying from 0.34 to 1.7 International Units. Likewise it is impossible to interpret, in any units, determinations of the vitamin A potency of butterfat involving the determination of the colorless vitamin A itself by spectrophotometry. Despite these difficulties, an attempt is made here to compare, so far as possible, the results obtained for the vitamin A potency of butterfat from cows fed in various ways; and only those results are used that were obtained by the Sherman method or are expressible in Sherman units.

Apparently the grains in the ration have no effect on the vitamin A potency of butterfat, even the effect of yellow corn being negligible, as is also that of cottonseed hulls or beet pulp; and the effect of hays, silages, and pasture depends on the amounts of carotene they supply. Recently the Bureau of Dairy Industry laboratory at Beltsville has published data (*1244*) on the carotene content of the various grades of some of the market hays and of corn silage prepared under various conditions. These results may be taken as an index of the effect of these feeds on the vitamin A potency of milk and butterfat. These data, along with some from the literature, are summed up in table 3.

TABLE 3.—*Carotene content of various cattle feeds*

Feed	Carotene content			
	Dry weight per kilogram		Weight per kilogram as fed	
	Range	Average	Range	Average
Green growing material:	*Milligrams*	*Milligrams*	*Milligrams*	*Milligrams*
Bluegrass	424–662	567		
Alfalfa	271–412	332		
Artificially dried material: [1]				
Grass [2]	266–479	359		
Alfalfa-leaf meal			76–244	151
Silages:				
Grass, A. I. V.[2]	381–522	427		
Alfalfa, A. I. V	(3)	(3)	(3)	
Corn	41–56	50	1–40	14
Alfalfa hay:				
U. S. No. 1 in color			19–121	44
U. S. No. 2 in color			12–19	15
U. S. No. 3 in color			1–11	4
Timothy hay:				
U. S. No. 1 in color			8–36	21
U. S. No. 2 in color			8–11	9
U. S. No. 3 in color			1–11	5
Carrots, garden, yellow	268–1,692	914	36–132	91

[1] Not much carotene is lost in artificial drying.
[2] Watson et al. (*1190*).
[3] Nearly the same as fresh material.

A cow on a ration containing 10 pounds of U. S. No. 1 alfalfa hay and 30 pounds of corn silage may consume over 500,000 International Units of carotene daily, and secrete only about 30,000 International Units of vitamin A in her milk. In fact some results indicate an even poorer utilization of carotene in milk secretion.

Colostrum may be as much as 10 times as rich in vitamin A as later milk from the same cow. The vitamin A value of colostrum has been determined by various methods. The data in table 4 are from biological determinations.

TABLE 4.—*Vitamin A potency per gram of colostrum from cows of various breeds on rations without pasture and with rye pasture* [1]

Day of lactation	Cow 190, Holstein, no pasture		Cow 241, Ayrshire, no pasture		Cow 220, Ayrshire, rye pasture		Cow 471, Guernsey, rye pasture	
	Whole product	Fat	Whole product	Fat	Whole product	Fat	Whole product	Fat
	I. U.	*I. U.*	*I. U.*	*I. U.*	*I. U.*	*I. U.*	*I. U.*	*I. U.*
First	16.2	426	18.2	356	25.4	747	27.6	530
Second	9.0	230	20.4	227	12.3	240	19.3	378
Fourth	2.9		4.1				4.4	
Sixth					1.9			
Seventh	2.5		2.8					
Ninth							2.3	
Twelfth					1.8			
Fourteenth	2.0		1.7					
Sixteenth							1.8	
Twenty-fifth			2.1	49	1.2	26		
Twenty-sixth	2.3	50					1.7	40

[1] Data from Kramer, Blair, Kunerth, and Riddell (*646*).

It is obvious that (1) a cow is very wasteful of the sources of vitamin A in her diet, and (2) the requirements for vitamin A depend on the type of milk desired. The milk should certainly contain enough vitamin A for the normal growth of the suckling calf. Using the night-blindness test, Guilbert, Miller, and Hughes (*447*) of California found that the minimum carotene requirement for the bovine was supplied by about 25 to 30 micrograms daily of carotene, or 6 to 8 micrograms of vitamin A itself, per kilogram of body weight. Three points in this excellent work are of interest here: (1) These supplies of vitamin A or its precursor permitted "excellent growth"; but "the animals used varied in age from 7 months to 4 years." There is no evidence to show that such allowances of this vitamin would be adequate for normal growth during the early suckling period when the rate of growth is very much more rapid. No published data on the requirements of the calf during the first few months of life are now available, but it seems safe to predict that they will be found to be higher than those of animals 7 months old and older.[4] (2) Two of the cows exhibited no symptoms of vitamin A deficiency "even though their milk was so deficient in vitamin A that their nursing calves developed definite night blindness and other deficiency symptoms" (*384*). Cows receiving the minimum requirements as indicated by the night-blindness test had abnormal calves; when this allowance was tripled or quadrupled normal calves were born.

Meigs (*775*) has estimated that a cow requires a minimum of about 60 to 80 milligrams of carotene daily in her diet to bring about normal calving. This is close to 150 micrograms of carotene per kilogram of body weight. The carotene in this work of Meigs, as well as in that by Guilbert et al., was estimated by a modification of the Willstätter and Stoll procedure (*447*), which has been shown to give an erroneous value for the carotene in feeds, as pigments other than carotene are not completely removed from it in estimating it by such procedures.

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[4] This statement is based on preliminary unpublished results in the Bureau of Dairy Industry laboratory at Beltsville, Md.

Allowing as well as possible for this discrepancy, this carotene requirement for normal calving is not far from (and certainly not less than) 90 to 100 micrograms of pure β-carotene daily per kilogram of body weight. When fed to the dam, however, this does not appear to permit optimum growth in the nursing calf.[5] The amount of carotene required for good calf growth, therefore, must exceed that in milk produced by cows fed at the minimum level necessary for normal calving. A more definite statement must await further work.

THE B VITAMINS

Animals when lactating require larger quantities of the B vitamins than when not lactating. Their health, the capacity to lactate, the amount of milk secreted, and the composition of the milk are affected by the supply of these vitamins that are available for lactation. This has been demonstrated particularly for vitamins B_1 and B_2 (G).[6] Whether this increased need is simply for the vitamins to put into the milk or whether they take part particularly in some of the metabolic processes associated with milk secretion is unknown.

Thiamin has been shown to take part in carbohydrate metabolism, particularly in the disposition of certain intermediate products (pyruvic acid and lactic acid) in the break-down of carbohydrates. The thiamin requirements of animals appear to be correlated with their food consumption, especially with their consumption of carbohydrates. As the food intake is greatly increased during lactation, it has been suggested that a very great increase in thiamin requirements might be expected during this period, in addition to the amount required for the milk itself. This argument, however, is not convincing because too little is known regarding the relation of thiamin to the two main processes involved in the increased carbohydrate metabolism during lactation, namely, the conversion of glucose into lactose and the increased conversion of glucose into fat.

The fact that the drain of lactation predisposes nursing human mothers to beriberi, that infantile beriberi is frequent in the young of human mothers on diets low in vitamin B_1, and that mother rats on diets low in this vitamin fail to rear their young, do not in themselves necessitate the assumption that vitamin B_1 is required in excessive amounts in metabolic functions during lactation, in addition to what is necessary to put into the milk.

The observation of Richter and Barelare (*959*) that self-fed rats select proportionately more yeast during lactation is exceedingly interesting, but it is not specific enough, especially regarding quantities, to throw light on the functions that the B factors in the yeast may be serving; but the work of Evans and Burr (*347*) and others (*740, 1109*), showing that lactating rats require about five times the vitamin B_1 necessary for normal growth and reproduction, has been interpreted to mean that the increased requirements for lactation are considerably in excess of the amount of this vitamin put into the milk.

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[5] CONVERSE, H. T., and MEIGS, E. B. CAROTENE AND VITAMIN A IN THE NUTRITION OF DAIRY CALVES. [U. S.] Bur. Dairy Indus. Mimeo. No. 645, 4 pp. 1934.

[6] So far as practical, vitamin B as used here refers to the original undifferentiated vitamin B complex, vitamin B_1 to the undifferentiated heat-labile fraction of this complex, thiamin to this particular compound in the vitamin B_1 complex, vitamin B_2 or vitamin G to the undifferentiated heat-stable fraction of the original vitamin B complex, and riboflavin to this particular compound in the vitamin B_2 (G) complex.

Vitamin B_2 (G) is also needed in considerable quantity (*565*) during lactation.

Vitamin B_1 deficiency leads to a reduced food consumption, and Sure and Walker (*1110*) state that "lactating rats given diets deficient in vitamin B consume approximately 50 percent less food daily than nursing mothers receiving the same rations fortified with an abundance of this vitamin." As already noted with the cow, this reduction in food consumption in itself would seriously limit milk production and probably, as with the cow, would reduce the percentage of protein in the milk secreted. Sure and Walker carried out an experiment to determine whether this reduced food consumption accounts completely for the death of suckling rats that are nursed by mothers on diets low in vitamin B_1. The mother rats were fed in pairs and allowed to nurse litters initially of the same number of young. Both mothers of a pair were fed the same amount of food, containing in each case 10 percent of yeast as their source of B vitamins. In one case this yeast was heated in an autoclave to destroy vitamin B_1; in the other it was not. Thirty-two of the forty-two young nursed by the mothers that were fed the autoclaved yeast failed to survive the suckling period, whereas only two nursed by the mothers fed the unautoclaved yeast died during this period.

It is obvious that the B vitamins are needed in lactation, that at least vitamin B_1 is needed in relatively very large quantities in comparison with the requirements for growth and reproduction, and that suckling young may suffer from severe dietary deficiencies when their mothers are on diets low in vitamin B_1.

Despite these facts showing the importance of the B vitamins in lactation, Theiler, Green, and Viljoen (1915) (*1132*), working with cattle in South Africa, observed no symptoms that they recognized as evidence of vitamin deficiency when they fed rations very low in what was then known as vitamin B. They conclude: "It may be cattle are capable of synthesizing their own vitamin in virtue of the extensive flora of their intestinal tract." About 11 years later, Bechdel, Eckles, and Palmer (*75*) also came to this conclusion. They showed that calves may "grow normally to maturity and produce normal offspring on a ration that carries an insufficient amount of the vitamin B complex to support growth and well being in rats." Bechdel and Honeywell (*78*) also showed "that vitamin B in milk is not dependent upon the presence of this vitamin in the ration of the cow." The B vitamins are synthesized by the higher plants, yeasts, and certain bacteria. Rats sometimes recover spontaneously from vitamin B deficiencies, presumably because of the synthesis of these vitamins in their intestinal tract; and Bechdel, Honeywell, Dutcher, and Knutson (*79*) demonstrated that this process occurred in the paunch of cattle.

The calves on the vitamin B-deficient rations used by Bechdel et al. grew to maturity, bore young, and started to lactate, but continuous lactation beyond a very few weeks was impossible. The investigators tried in several ways to overcome this failure in lactation and the failure in appetite (anorexia) that preceded or accompanied it. The feeding of marmite, a vitamin B preparation made from yeast, failed. Only hay was successful. The active principle in the hay responsible for this success has never been identified. It may have been some factor in the vitamin B complex that was not formed in adequate amounts in the paunch and did not occur in adequate amounts in the marmite fed to meet the augmented requirements for lactation. This requires investigation; and the conclusion "that the vitamin B in milk is not dependent upon the presence of this vitamin in the ration of the cow" (*78*) may apply necessarily, as a result of this work of Bechdel et al. (*79*), to only one factor of the vitamin B complex.

It is impossible at the present time to state definitely whether it is necessary to supply any of the B vitamins in the rations of lactating dairy cattle.

The work on the B vitamins in milk done prior to about 5 years ago is reviewed in the Fundamentals of Dairy Science by Associates of L. A. Rogers (*42*). It may be summed up as follows:

(1) Cow's milk is not a particularly rich source of vitamin B_1 relative to the requirement of the human being or the rat; goat's milk has about the same potency; and human milk contains somewhat less vitamin B_1 than either cow's or goat's milk. According to the data then at hand (1935), cow's milk contained from 0.1 to 0.2 Sherman units of vitamin B_1 per milliliter with an average of possibly 0.13.

(2) The concentration of vitamin B_1 in cow's milk, goat's milk, and human milk is not readily increased above certain maximum limits; and, so far as diet is concerned, these limits are reached on rations that are ordinarily used and considered adequate. The evidence with cow's milk would indicate that even with rations very low in vitamin B_1, the concentration of this vitamin in the milk is not materially affected; but with man and with rats vitamin B_1 deficiency in the diet of the mother may seriously affect the nutrition of the young. Some evidence tends to indicate that this may be due to a reduced concentration of vitamin B_1 in the milk; but in other instances there is evidence that the volume of milk is affected, as might be expected from the reduced food consumption of the mother that would accompany such a deficiency in her diet. The vitamin B_1 in cow's milk is unaffected by the breed of the cow, stage of lactation, or season of the year.

(3) Much more of cow's milk (possibly two to three times as much) is required to supply the vitamin B_1 than to supply the vitamin B_2 (G) for equivalent rates of rat growth. The same volume of milk, therefore, contains two to three times as many units of vitamin B_2 as of vitamin B_1.[7] Human milk also was found to contain two to three times as many units of vitamin B_2 as of vitamin B_1. Materials relatively rich in vitamin B_1 supplement the B vitamins in cow's milk when fed to human beings or rats; but autoclaved yeast, which is rich in vitamin B_2 (G), does not do so. The cereal foods that have not been deprived of their vitamin B_1 by some method of processing are therefore good supplements for the B vitamins in cow's milk so far as vitamin B_1 is concerned, and milk supplements the vitamin B_2 (G) deficiency in the cereals. The concentration of vitamin B_2 (G) in cow's milk varied from 0.2 to 1.00 Sherman units per milliliter in different laboratories (average, 0.55 Sherman units).

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[7] Using either the Sherman growth unit of 3 grams per week or the "normal" growth unit of 50 to 60 grams in 5 weeks, as used in English laboratories.

(4) The concentration of vitamin B_2 (G) in cow's milk and human milk may be increased 50 to 75 percent by increasing the vitamin B_2 content of the diet.

(5) Cow's milk is effective in the treatment of pellagra. This was shown by Casal about 200 years ago, by Roussel about 85 years ago, and in the work of Goldberger and collaborators in the United States Public Health Service in 1925 (*423*). It might be assumed, therefore, that cow's milk contains nicotinic acid, and any other dietary factor that may be connected with this disease.

Since this review by Associates of L. A. Rogers was written, work has been done on the concentrations of vitamins B_1 and B_6 in milk, and there has been considerable development in our knowledge of its content of vitamin B_2 (G). The more pertinent work that has come to the writer's attention may be summed up briefly as follows:

(1) The concentration of vitamin B_1 in milk has now been estimated chemically by different workers. In one paper (*936*) the vitamin B_1 was 0.06, 0.11, and 0.25 International Unit per milliliter respectively in three samples of raw milk; in another paper (*56*) from the same laboratory, a figure of 0.23 is given; while other workers (*546*) with a similar procedure found 0.20 unit. Williams and Spies (*1229*) have calculated that cow's milk contains 0.45 milligram of vitamin B_1 per liter of milk. If the data were compared by using the relations between the different B_1 units given by Williams and Spies, it would be noted that there is a wide variation in the figures for the concentration of this vitamin in milk. To what extent these differences actually exist in the milk or are due to inaccuracies in the analytical methods used is at present impossible to say. Elvehjem, in a recent review (*325*), states that cow's milk contains on an average 125 International Units of vitamin B_1 per quart.

(2) Knowledge of riboflavin in milk has progressed rapidly in the last 5 years. Various workers had puzzled over the greenish-yellow pigment in the whey of milk. According to Palmer (*42*) mention of this pigment—

> appears in the scientific literature as early as 1784, but the first attempt to purify it was made nearly 100 years later when the pigment isolated was given the name lactochrome . . . One of the outstanding characteristics of milk serum from cow's milk . . . is the greenish-yellow fluorescence of the pigmented solution.

This greenish-yellow fluorescent pigment is unstable toward light in solutions that light can penetrate, and exists in nature sometimes free and sometimes combined with protein. These properties undoubtedly led to confusing results with early workers; but in 1933, Kuhn and his collaborators (*651*, *652*) isolated this greenish-yellow fluorescing pigment from milk and egg white. It proved to be what is now known as riboflavin (that is, a yellow chemical, flavin with a ribose sugar group in its molecule). (See Vitamin Needs of Man, p. 221.)

A year before this report, Warburg and Christian (*1180*) reported the discovery of a new oxidation enzyme which they isolated from yeast. They found that they could break this enzyme up into a protein, phosphoric acid, and a greenish-yellow fluorescing pigment, which later was also proved to be riboflavin. This enzyme, which occurs generally in living cells and is thought to take part in certain phases of the oxidative processes in them, is a combination of phosphoric acid and riboflavin with a protein. The work on riboflavin, the chemistry of riboflavin, and the relation of riboflavin to this enzyme has been recently reviewed by Booher (*135*), who herself took part in the work leading to the identification of riboflavin as the yellowish-green fluorescing pigment in the whey of milk; further references will be found in her review.

A number of determinations of the concentration of riboflavin in milk have recently been made— some of them by chemical and physicochemical methods. Workers at Manhattan, Kans. (*1211*), with the same samples of milk, found 2.30 milligrams of riboflavin per liter by the Bourquin-Sherman biological method, and 2.14 milligrams by a method in which they measured it by its fluorescence. Their average for all samples (*647*, *1211*, *1212*) except colostrum analyzed biologically was 2.15 milligrams per liter, and for samples measured by the fluorescence method, 1.8 milligrams. These figures correspond approximately to 0.72 and 0.6 Bourquin-Sherman units per milliliter. Neuweiler (*848*), and Houston, Kon, and Henry (*546*) by similar fluorescence measurements found, respectively, 1.33 milligrams and 1.0 to 1.5 milligrams per liter, corresponding possibly to 0.44 to 0.42 Bourquin-Sherman units per milliliter. By the same method Houston, Kon, and Henry found 0.85 milligram per liter in guinea pig milk and 4.0 milligrams in rat milk. Kuhn et al. (*654*) obtained 1.0 milligram per liter in cow's milk. Sherman and Lanford in a recent review (*1053*) give 67±3 Bourquin-Sherman units (with a coefficient of variation of 28) as the average riboflavin content of per 100 grams of milk. This figure represents 17 available quantitative results of 10 independent investigations.

According to György (*451*) cow's milk contains about three times as much riboflavin as human milk; while Neuweiler's figures (*848*) for cow's milk were three to seven times those for human milk. Possibly, therefore, some samples of human milk may be relatively less potent in riboflavin than in vitamin B_1, when measured by the growth of rats; but Neuweiler's results agreed with previous work in showing that the riboflavin content of human milk may be increased by administration of this vitamin.

TABLE 5.—*Comparison of vitamin B_2 in colostrum and in later milk from the same cow*

Cow No.	Vitamin B_2 per liter of milk on lactation day indicated			Total vitamin B_2 in milk on—		
	First day	Fifth day	Thirtieth day	First day	Fifth day	Thirtieth day
	Milligrams	*Milligrams*	*Milligrams*	*Milligrams*	*Milligrams*	*Milligrams*
118	4.5		1.7	14		36
373	4.5		1.7	12		29
197	6.7	3.7	2.4	13	79	69
378	4.4	3.3	2.3	12	36	30

[1] Average vitamin B_2 in milk of herd was 2 milligrams per liter.

Kramer, Gardner, Kunerth, and Riddell, at Manhattan, Kans. (*647*), compared the riboflavin content of colostrum with that of later milk from the same cows. These results are shown in table 5. Workers in this same laboratory also analyzed milk from cows of different breeds (*1212*). They obtained the following riboflavin content in milligrams per liter of milk: Ayrshires, 1.17; Holsteins, 1.40; Guernseys, 1.53; and Jerseys, 1.73. Until more is known regarding the conditions affecting the concentration of riboflavin in milk and the chance variations with different groups of the same breed on the same diet, it cannot be concluded that there are generally real differences in the riboflavin content of the milk of different breeds of cows.

(3) In one of the most interesting experiments on the B vitamins in milk, György (*451*), now working at the Babies' and Children's Hospital and the Department of Pediatrics at Western Reserve University in Cleveland, compared the riboflavin and vitamin B_6 concentrations in human milk and cow's milk. He used rats as the experimental animals. The basal diets in all cases contained crystalline vitamin B_1. When he estimated the potency of milk as a source of vitamin B_6, the basal diet also contained pure riboflavin; and on the other hand, when he determined the riboflavin concentration in milk, he added a vitamin B_6 concentrate to the basal ration in addition to the vitamin B_1. The rats were young, and their rates of growth, when the milk was added to supply the missing factor, was taken as a measure of the potency of this factor in the milk. He concluded that cow's milk is about equally potent in riboflavin and vitamin B_6 and that human milk has about the same potency in vitamin B_6 as cow's milk, but that cow's milk is three times as potent as human milk as a source of riboflavin. It is obvious that when the milk was added to the basal rations of these rats as a source of riboflavin in the one case and of vitamin B_6 in the other, it may not only have supplied these particular factors but also more or less of any other growth factors in milk that were deficient in the basal ration. That cow's milk when supplemented by iron, copper, and manganese contains still unknown factors essential for growth is attested by the fact that rats fed cow's milk supplemented with these minerals make "average daily gains very similar to those made by rats on an ordinary ration" (*323*). Whether or not these factors would be missing in the basal ration used by György is a question.

VITAMIN C

Of the animals studied, only man and the other primates and the guinea pig appear to have no capacity to synthesize vitamin C (ascorbic acid). Where, how, and from what this vitamin is made in the animal organism are unknown as well as the conditions that influence synthesis. Thurston, Palmer, and Eckles (*1137*) first studied the role of vitamin C in the nutrition of cattle. Their conclusions were as follows:

> 1. Vitamin C can be demonstrated in the livers of calves fed for 1 year on a ration capable of producing scurvy in guinea pigs within 30 days.
> 2. Heifers fed from birth on a scorbutic diet secrete appreciable quantities of vitamin C in their milk
> 3. The absence of vitamin C from the diet apparently does not interfere with reproduction in cattle.
> 4. Vitamin C is probably synthesized within the boby of the bovine. Evidence is supplied to indicate that the digestive tract is not concerned in this synthesis.
> 5. The results of these and our previous experiments indicate conclusively that the bovine does not require vitamin C [in the ration] in quantities that can be detected by tests with guinea pigs.

These conclusions regarding the necessity of supplying vitamin C in cattle rations have been generally accepted. The following quotation from an article by Sharp (*1032*) at Cornell University may add to the understanding of this situation:

> Plant tissues which contain ascorbic acid apparently also contain an ascorbic acid oxidizing enzyme which is liberated when the cells are crushed. The enzyme in some plants is very active. For example, the large amount of ascorbic acid present in cabbage is completely oxidized [and therefore destroyed] in 5 minutes after the previously frozen raw cabbage cells are disintegrated. While the feed is masticated and stored in the rumen by the cow, all the ascorbic acid it contains is probably oxidized. Therefore the cow and animals with similar digestive systems, and possibly birds, must either synthesize ascorbic acid or reverse the oxidation.

If the oxidation of the vitamin C goes too far the process is irreversible and the vitamin is completely lost. To what extent vitamin C is ultimately lost in the rumen of the cow is unknown.

Despite the above facts, it is still a disputed question as to whether the quantity of vitamin C in the diet of a cow may affect the concentration in her milk. To interpret results in connection with this problem, it is necessary to consider some of the properties of vitamin C itself when dissolved in milk. Although milk freshly drawn from the cow may contain 20 to 25 milligrams of vitamin C per liter, 457 samples of pasteurized commercial bottled milk 3 days old, obtained from various distributors in different cities, was found to contain only 2.2 milligrams per liter, and 63 samples of raw milk contained only 7.9 millgrams per liter (*1032*). Vitamin C in milk is therefore unstable. Some of the conditions that affect the rate of its destruction are indicated by Sharp (*1032*):

> Variations in the rate of oxidation of ascorbic acid in milk can be explained best by assuming the presence of an ascorbic acid oxidase [the enzyme already mentioned], the action of which is markedly accelerated by traces of dissolved copper.

Sharp reports the vitamin C content of milk that when fresh contained 20.1 milligrams of vitamin C per liter as 11.3 milligrams per liter after storage for 3 days at 35.6° F.; the vitamin C content of milk pasteurized at 143° to 145° F. for 30 minutes and then stored was 11.0 milligrams; but when thus pasteurized with a little copper added and then stored, the vitamin C content was only 1.7 milligrams per liter. According to Sharp the enzyme taking part in the destruction of vitamin C is destroyed by heating milk for half a minute or longer at 170° F., and copper does not affect the destruction of vitamin C so readily without this enzyme. Thus, when some more of the same milk used above was pasteurized by heating 10 minutes at 170° and stored as above, its vitamin C content was 15.7 milligrams per liter when no copper was added, and 12.4 milligrams per liter when copper was added.

Another factor that greatly affects the destruction of vitamin C in milk is exposure to light. Kon and Watson (*643*) report that as much as 50 percent of the vitamin C in milk may undergo oxidation when exposed for one-half hour in sunlight and then kept for 1 hour in darkness.

Some of the products of the oxidation of vitamin C may be changed back to vitamin C in the animal body and be used as such. One of these oxidation products is called oxidized ascorbic acid, or dehydroascorbic acid—that is, ascorbic acid that has lost two of the hydrogen atoms in its molecule. Other oxidation products of vitamin C have no physiological value; and none of the products of oxidation, whether they are physiologically active as vitamin C or not, react with some of the reagents used in the chemical determination of this vitamin in milk.

It is obvious that determinations of the vitamin C content of milk that do not take these properties into account are now of little value, and that conclusions based upon them are not valid.

Kon and Watson (*644*), using methods that reduced these sources of error to a minimum, very carefully estimated the quantity of unoxidized vitamin C in freshly drawn cow's milk as compared with the total vitamin C, including the reversibly oxidized vitamin. The unoxidized vitamin C was about 21.7 and the total 22.1 milligrams per liter, indicating that practically no reversibly oxidized vitamin C occurs normally in freshly drawn cow's milk. The cow secretes only unoxidized vitamin C. Knight, Dutcher, and Guerrant (*638*) at Pennsylvania State College have recently obtained the same result as Kon and Watson, the figure being 22.9 milligrams per liter for both the unoxidized vitamin C and the total including reversibly oxidized vitamin C. All of the vitamin C in freshly drawn milk, therefore, is in the ordinary unoxidized or reduced form, and reacts to reagents used for its estimation. When workers report 8 milligrams of unoxidized vitamin C per liter in milk and 16.9 milligrams for the total including the reversibly oxidized material, as some workers have done, it means that they are not measuring the vitamin C content of normal fresh milk as secreted by the cow. It also means that the figure for the ordinary vitamin C alone in such milk is not a measure of its physiological value because the reversibly oxidized material may also be used as vitamin C.

Kon and Watson (*644*) have also analyzed milk produced at different times of the year (between January and July) and on different diets. They followed a uniform procedure throughout, obtaining the milk after it had passed over a cooler shortly after the morning milking. The average figures for the ordinary reduced vitamin and the total reduced and reversibly oxidized material, respectively, for stall-fed cows were 20.6 and 23.5 milligrams per liter, and for milk from cows on pasture they were 20.6 and 23.5 milligrams per liter. The results indicate definitely that there is no difference in the vitamin C content of these milks as the result of a change of season or a change of ration. Riddell, Whitnah, Hughes, and Leinhardt (*964*) at Manhattan, Kans., have obtained similar results insofar as the effect of diet on the vitamin C content of milk is concerned. For 74 samples of milk from cows on a dry ration and silage they found 25.8 milligrams of vitamin C per liter; for 57 samples from cows on pasture, 26.5 milligrams per liter; and for 66 samples, when the cows were on a dry ration and received no silage, the vitamin C content was 26.8 milligrams per liter. These results were obtained by chemical methods of assay. In other reports from this same laboratory (*1213*, *1214*), they found 25.9 milligrams of vitamin C per liter for the average of 502 samples of milk from 55 cows; and, as an average for the herd at Manhattan from October to April, they give 25.5 milligrams of vitamin C per liter. Holmes, Tripp, Woelffer, and Satterfield (*530*) have recently reported results for 661 samples of certified milk from 55 Guernsey and Jersey cows. The averages for the vitamin C, separated according to breed, was 20.5 and 18.2 milligrams per liter, respectively. Other results, similar to those quoted here, occur in the literature.

On the other hand, some workers report very different figures for the vitamin C content of milk, and examination of some individual results shows a wide variation between separate determinations. Rasmussen, Guerrant, Shaw, Welch, and Bechdel (*947*), for instance, report the average vitamin C content for each of several breeds of cattle as varying from 10 to 14.8 milligrams per liter. Kon and Watson, in referring to this work, appear inclined, however, to attribute the results to faulty technique, and the Pennsylvania workers have since published an improved procedure for sampling milk for these analyses. Differences in the vitamin C content of milk have also been attributed to changes in the season of the year, but the results have been conflicting. Some differences have been noted between breeds, but if they actually occur, they are negligible. Neuweiler (*847*) has presented data showing that the vitamin C content is low in milk from pregnant animals. The vitamin C content of colostrum has been reported as possibly somewhat higher than that of later milk from the same cows.

Neuweiler gives the vitamin C content of human milk as from 40 to 70 milligrams per liter, and the figures of most workers would come within this range. Human milk, therefore, is ordinarily decidedly richer in this vitamin than cow's milk. Neuweiler also demonstrated that the amount of vitamin C in human milk may be definitely increased by administration of very large doses of vitamin C to the mother.

Rasmussen, Bogart, and Maynard (*946*), have recently published the results of work at Cornell University. The details are not available. The results indicate that the vitamin C content of the milk of a ewe may vary from 25 to 40 milligrams per liter and be increased 50 percent by subcutaneous injection of 5 grams of vitamin C into the animal. In the case of one cow, they obtained a similar increase in the vitamin C content of the milk by injecting 24 grams of vitamin C, and a significant increase in the milk of another as a result of the injection of only 12 grams. Mare's milk varied from 27 to 115 milligrams per liter, and appeared to be affected by the amount of vitamin C in the feed; but the authors prefer to leave final conclusions as to the relation between the vitamin C in the diet and the milk in the case of the mare to further results with biological methods. Guinea pig milk apparently contains about 290 milligrams of vitamin C per liter. On dry feed with a limited amount of green material, it was about 110 milligrams per liter, but with more green feed it was 397 milligrams per liter; and with green feed and subcutaneous injection of additional vitamin C, about 710 milligrams per liter is reported. These workers also demonstrated that they could affect the tendency to scurvy in young guinea pigs by altering the vitamin C content of the diet of the mother, showing biologically, as well as chemically, that the vitamin C in the milk of this animal is affected by the amount of vitamin C in its diet.

In this work, except when otherwise indicated, chemical methods were used for the assay of the vitamin C. Despite the preponderance of evidence with these methods indicating that the vitamin C content of cow's milk is independent of the diet of the cow, the fact must be recognized that many of the earlier workers in this field, using biological methods of assay, obtained exactly the opposite result. Sometimes milk from cows on pasture was found to contain two to three times as much vitamin C as that from cows receiving only dry feeds, and milk from cows receiving silage was reported to be high in this vitamin. These results have not been comparable among themselves. Sometimes where they have appeared conflicting, the experimental conditions have been quite different; and most of the work was carried out before the precautions that are now known to be necessary were recognized. Nevertheless, they indicate that there may possibly be dietary conditions which sometimes affect the concentration of vitamin C in cow's milk. More work, however, is certainly necessary to demonstrate clearly whether or not this may be true.

In closing this discussion of vitamin C in milk it may be said that (1) fresh cow's milk contains on an average about 25 milligrams of vitamin C per quart; (2) frequently the vitamin C content of milk as delivered to the consumer is very much less than this; (3) loss as a result of pasteurization depends on whether or not practical precautions are taken.

VITAMIN D

Numerous factors, both dietary and physiological, affect the utilization of calcium and phosphorus in the animal organism. Among these is vitamin D, the antirachitic or rickets-preventing vitamin. Several laboratories have studied the vitamin D requirements of growing cattle. Symptoms of vitamin D deficiency can readily be produced experimentally in these animals when they are reared in the dark on rations especially deficient in this factor that is, under conditions that need not and seldom do prevail in practice. The requirements have generally been measured and expressed in terms of the number of units of vitamin D in the feed that are necessary to prevent or cure these symptoms; but they could as well be determined and expressed in terms of the amount of exposure to light of measured intensity and quality that would have the same effect. Little is known regarding the effect of the calcium and phosphorus content of the ration upon this requirement for vitamin D in cattle; but, whatever it may be, their vitamin D requirement is readily met by ordinary rations or by a little exposure to direct or indirect sunlight. (See the article Practical Feeding and Nutritional Requirements of Young Dairy Stock, p. 636.)

Although there are other feed and physiological factors that complicate viewpoints on the relation of vitamin D to the metabolism of calcium and phosphorus with milking dairy cattle, it is probable that these animals, like the growing calf, actually require vitamin D; but that these requirements, both for the metabolism of the animal herself and for the vitamin D to put into her milk, are readily met either by the ration or by exposure to light in any ordinary management practice. It is true that at least some mammals tend to lose calcium and phosphorus from their bodies early in lactation and that in the cow, according to results obtained by various workers, these losses are unaffected by the administration of additional vitamin D either in the feed or by greater exposure to light. It is also true that the rate of loss of these elements early in lactation appears to be less on rations of hays that have been so cured as to retain much of their green color than on sun-bleached hays, which are actually richer in vitamin D; and further, the amount of vitamin D that a cow gets does not affect the concentrations of calcium and phosphorus in the milk. Nevertheless, Wallis (*1179*) reports symptoms of vitamin D deficiency in milking cows when kept under quite extraordinary conditions, as in the work with young dairy stock; and he reports the relief of these symptoms by administration of vitamin D. Finally, that a milking cow can utilize vitamin D in her feed, or can make vitamin D as a result of exposure to light and use what she has made, is evident from the fact that either an increase of the vitamin in the feed or an exposure of the cow to light may increase the concentration of vitamin D in the milk.

A number of workers have shown that the vitamin D content of cow's milk is greater in summer than in winter. This is demonstrated particularly impressively by the results of Bechtel and Hoppert at the Michigan Agricultural Experiment Station (*81*). For 2 years they made monthly determinations of the vitamin D content of milk fat from the higher-producing cows in the Holstein and Jersey herds at that station. They also followed for a year the vitamin D content of the milk fat with the 5 highest-producing Holsteins in this herd; and in addition they obtained samples of the Michigan State College creamery butter monthly for a year and analyzed them. This creamery butter was produced by approximately 15 herds consisting of grade Holstein cows. The conclusions of these workers are as follows:

> (1) The monthly assay of milk fats from several sources over a period of 2 years shows that milk may vary as much as 900 percent in antirachitic potency. Highest values were obtained during July, August and September and lowest usually in February. Vitamin D values varying from 4.8 to 43.8 U. S. P. [United States Pharmacopeia] units per quart of milk were observed in the case of Guernsey milk, whereas the extreme values for Holstein milk were 3.1 to 27.7 U. S. P. units per quart.
>
> (2) The close correlation between the antirachitic potency of milk and the amount of available sunshine indicates that the exposure of cows to sunlight is the major factor contributing to the vitamin D content of milk.

Fresh green pasture grass contains little or no vitamin D. Evidence that exposure to sunlight is the major factor bringing about the difference between the vitamin D content of summer and winter milk has been presented in a paper by Campion, Henry, Kon, and Mackintosh (*189*). This evidence is summed up in table 6.

These results on the influence of sunlight on the vitamin D content of milk do not mean that it may not be influenced by the use of feeds rich in vitamin D such as irradiated yeast and cod-liver oil, but they indicate that the latter method of increasing the vitamin D content of milk is very wasteful and generally impractical. A discussion of the vitamin D value of milk and the factors affecting it may be found in a bulletin by Olson and Wallis (*873*).

TABLE 6.—*Effects of diet and of exposure of animal to light on vitamin D secretion in milk*

Treatment of cows	Vitamin D of—		Total vitamin D secreted daily
	Milk	Butter	
	International Units per kilogram	*International Units per gram*	*International Units*
Kept indoors on winter rations	8.3	0.27	110
Kept outdoors on winter rations	26.0	.88	313
Kept outdoors on pasture	17.0	.46	252
Kept indoors and fed freshly cut pasture grass	5.3	.15	52

GLANDS, HORMONES, AND BLOOD CONSTITUENTS —THEIR RELATION TO MILK SECRETION

WHAT part do the endocrine glands play in the secretion of milk? Do the proteins, the fatty acids, and the sugar in milk come directly from corresponding materials in the blood stream of the lactating animal? These questions touch some of the deepest mysteries of milk production. The authors delve into them boldly, attempting to draw a clear line between known facts and speculation.

ENDOCRINE FACTORS

by M. H. Friedman [1]

IN THE past few years the advances in the field of endocrinology have come so rapidly as to make dizzy even the professional endocrinologists, let alone the interested lay person who tries to glean some information about the endocrine glands from the maze of startling announcements coming from the laboratories. Unfortunately, these startling announcements are not always limited to the observed facts. They are all too frequently the interpretations reached from a flying start on a few pieces of experimental evidence and a recklessly long jump into the thin air of pure speculation. There should be no objection to speculation. But the reader should be warned where knowledge ends and armchair science begins. An effort will be made in the present discussion to distinguish clearly between fact and fancy.

If the facts show anything at all they show quite clearly that from the standpoint of the endocrine control of milk secretion the cow is very much akin to all other animals. This is fortunate, for the cow is a very expensive experimental animal and yields results slowly. Most of the advances in the field of endocrinology have been made by experiments on small laboratory animals that yield results rapidly at low cost. Up to the present time every finding derived from these small animals has been verified by direct experiment on the cow whenever such an experiment has been possible. To date, there has been uncovered no significant difference between those life processes governing milk production in the cow and in the smaller animals. Although some minor differences between species may be encountered, there is every reason to expect, from our knowledge of other life processes, that the similarities will far outweigh the minor differences. The dairy farmer may expect to learn much from the physician, the doctor may expect to learn much from the farm, and both may confidently expect to learn very much from the laboratory worker experimenting on anything from goats to pigeons.

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DEVELOPMENT OF THE MAMMARY GLAND

Although some milk may be produced by an incompletely developed mammary gland (udder), such as is found in virgin animals or even in males, normal milk production requires such development of the gland as is found only in pregnant females.

Certainly the ovarian hormones must play an important role, but the ovaries of a pregnant animal are not known to secrete anything in addition to the two types of secretion elaborated during every heat cycle—estrin, a hormone found chiefly in the fluid of the follicles, and the corpus luteum hormone, found in the yellow body (corpus luteum). By the injection of estrin into spayed females, or into males, it is possible to bring about considerable mammary gland development; there is experimental evidence for this from all common laboratory animals and from the goat. This degree of development is sufficient for the production of some milk under the proper stimulus, but the condition of the gland is in no way comparable to that in the normally lactating animal. Regardless of the amount and duration of estrin injection, it has not been possible to produce thereby a fully developed gland in any species except the guinea pig.

This limited action of estrin is not surprising when it is recalled that the corpus luteum (yellow body) is an important factor during pregnancy. Indeed the injection into spayed animals of a proper combination of estrin and corpus luteum extract has enabled many workers to produce mammary glands that are more nearly comparable to those seen during the last part of pregnancy. This degree of success has led some workers to believe that the development of the mammary gland during pregnancy can be explained entirely on the basis of the influence of the two ovarian hormones.

The fact remains that the glandular development produced by the combined injection of estrin and corpus luteum extract is not an exact duplicate of the fully developed mammary gland. This is possibly merely a reflection of an improper balance between the amounts of the two hormonal preparations as injected in the experiments up to the present time. It is possible, however, that during pregnancy some additional factor is operating. The first suspicion would be that the contents of the pregnant uterus contribute something. Yet in a few species of animals, such as the dog and ferret, complete development of the mammary gland occurs when the uterus is empty, that is, during the period following heat that is called pseudopregnancy (false pregnancy). This condition in the dog and ferret is characterized by the presence in the ovaries of large yellow bodies for a period of time equal to the length of pregnancy. In the cow the life of the yellow body is less than the duration of one heat cycle. Unfortunately, the cow does not experience the phenomenon of false pregnancy, but if the bitch can develop her mammary gland without the help of her sons and daughters to be, there is probably no justification for crediting the cow with less ability in this direction.

It may be significant that either estrin or corpus luteum alone, or any combination of the two preparations, is unable to produce significant development of the mammary gland in animals from which the pituitary gland has been removed. Moreover, the injection of appropriate pituitary extracts into castrated animals leads to some increase in the size of the mammary gland. There is no reason to dispute these experimental observations, but it is well to pause before accepting all of the conclusions drawn from them. It has been concluded, for example, that the action of estrin and corpus luteum extract is not directly on the mammary gland, but only indirectly, through the pituitary, which releases the direct stimulating agent. At the moment, it is not easy to say how much the pituitary gland contributes directly to the growth of the mammary gland in the normal pregnant animal. Without attempting to assess the role of the pituitary in this matter, it is not necessarily true that estrin and corpus luteum extract work only through the pituitary. It is possible that the failure of ovarian extracts to work in the absence of the pituitary is due to some of the very widespread effects of removal of the pituitary (hypophysectomy) which have no direct connection with the fundamental processes underlying mammary-gland development. In order to separate fact from fancy, it is necessary to tabulate what appear to be demonstrable facts, which may be listed as follows:

1. The ovaries are essential for the full development of the mammary gland.
2. In spayed animals appropriate injections of estrin stimulate some glandular development, especially of the ducts, but do not lead to the type of glandular development seen during the latter part of pregnancy. Evidence for this has been obtained from most species of laboratory animals and from the goat.
3. Injections of proper combinations of estrin and corpus luteum extract into spayed animals induce a development beyond that obtainable with estrin alone (except in the guinea pig). This degree of development does not quite match that seen during late pregnancy.
4. The injection of estrin or corpus luteum extract, singly or in any combination, is not effective in animals with the pituitary removed according to evidence from mice, rats, and guinea pigs.
5. In the complete absence of the ovaries it is possible to produce some increase in size of the mammary gland by the injection of pituitary extracts.

FACTORS GOVERNING THE ONSET AND MAINTENANCE OF LACTATION (MILK SECRETION)

In contrast to the mechanisms involved in the development of the udder, the processes involved in lactation do not require the presence of the ovaries. In some species, such as the human being and the guinea pig, the ovaries may be removed during the latter part of pregnancy without interfering with either pregnancy or the onset of normal lactation. In any species, including the domestic animals, the ovaries may be removed during lactation without jeopardizing milk secretion. The essential stimulus for milk production comes from the anterior lobe of the pituitary. Removal of this gland, either late in pregnancy or during the early part of lactation, completely suppresses milk secretion, according to experimental evidence from all common laboratory animals and the goat. Conversely, the injection of appropriate pituitary extracts leads to the secretion of milk in males and virgin females, and to an increased milk secretion in lactating females that have passed the period of maximum production. There is evidence for this from all laboratory animals and from the goat, the virgin heifer, and the dairy cow in the declining phase of lactation. This lactation experimentally induced by pituitary extracts is not prevented by prior removal of the ovaries.

This stimulation of milk production by the injection of pituitary extracts may be of immense practical value in the future. For the present, however, the extracts available are not really suitable for use on the farm or in the clinic. These extracts lose their effectiveness when used repeatedly in the same animal. Still worse, the first or second injection of some of them may make the animal seriously ill. When these undesirable qualities have been eliminated it will be possible to use such extracts more extensively for valuable farm animals (and possibly for human beings). It should then be possible to evaluate their practical importance.

In the cow, lactation is not completely inhibited by pregnancy, but even in this species the female does not ordinarily come into milk until the pregnancy is terminated, either naturally or by abortion. Similarly in other species milk secretion sets in only after the uterus has been emptied. If for any reason the uterus is not emptied completely, as where parts of the young or of the membranes are retained, milk secretion is partly or wholly inhibited, according to evidence from rabbits and human beings. These relationships have been illustrated nicely by some experiments on rats. If the young are surgically removed from the uterus of a rat in the last part of pregnancy and the membranes are also removed, milk secretion sets in within 48 hours, which is far ahead of the normal schedule. If only the young are removed and the membranes are left behind, lactation does not occur. Or if the young and the membranes are completely removed and paraffin wax is inserted to take the place of the normal contents of the uterus, milk secretion does not occur. Even in a lactating animal it has been possible to suppress milk secretion by the insertion of wax into the uterus. Apparently any distention of the uterus has an inhibiting effect on milk secretion. It is possible that the effects of pregnancy on milk production in the cow are noticed chiefly after the fifth month because there is relatively little uterine distention before this time, the most significant increase in the uterine content of the cow occurring after the fifth month.

Another factor capable of inhibiting milk secretion is estrin. It has been demonstrated experimentally on all animals, including the goat and cow, that estrin injections during lactation decrease or completely suppress milk secretion. It is interesting to note at this point that a sharp decrease of estrin in the body may initiate milk secretion. For example, if a male guinea pig is injected with proper doses of estrin for a period of some 20 days (during the course of which the mammary glands develop), milk secretion does not set in during the injections but only after the injections are stopped. Similar results have been obtained by grafting ovaries into male guinea pigs. Milk secretion does not appear so long as the graft is in place. When the transplanted ovary is removed, milk appears.

It has been suggested by some workers that these effects are due to the release of the appropriate pituitary hormone in response to a sudden lowering of the body content of estrin. Interpreted in this manner, the inhibitory effects of estrin injection would be due to a restraint upon the pituitary gland which decreases the delivery into the blood of the hormone or hormones responsible for lactation. Such an explanation would appear to be a reasonable one and fits rather well with the observed facts. When, however, such interpretation is stressed to explain the effects of pregnancy on lactation and the ordinary delay of the onset of milk secretion until after parturition, it is well to be somewhat cautious.

It is true that the estrin content of the blood, urine, and body fluids is higher during pregnancy than at other times. It is also true that the estrin content decreases sharply after the young are born. It is not necessarily true that estrin is a major factor in depressing milk secretion during pregnancy. It so happens that during pregnancy the estrin found in the blood and body fluids is in a chemical combination that shows very little potency when tested on castrated rats—that is, the combination is relatively inactive. Moreover, the pregnant animal shows none of the effects that might be expected from the presence of large amounts of estrin; that is, the animal is not in heat, and the uterus and other sex organs show little or no response to the large amounts of estrin present. Although there are several possible explanations for this situation, the important thing is that there appears to be a lot of estrin on hand with nothing to do, or at least very little. If estrin is a major factor in regulating the appearance and disappearance of lactation, there would have to be some mechanism that would permit estrin to inhibit the pituitary at a time when it is unable to do much with other organs.

The influence of estrin on milk secretion when the estrin is able to do something may be seen in the lactating cow. There is definite evidence that the milk yield is decreased with each heat period. It is possibly significant that the reappearance of heat in the lactating cow occurs after the animal has passed the time of maximum production. It is also worthy of note that in most animals heat cycles do not occur during the early part of lactation and that in the absence of heat cycles the sex organs faithfully register the absence of the effects of estrin. In general, therefore, the influence of estrin is not exerted during the period of maximum lactation in any species. This influence is reasserted only after the peak of lactation has been passed. This association may be more than a coincidence and may ultimately furnish some partial explanation for the declining phase of milk secretion. That it will give a complete explanation is very unlikely in view of the relatively small and perhaps indefinite effects of castration during lactation. Up to the present time no one has been able to prevent the decline of lactation by castration.

The nervous system seems to be of prime importance in lactation. In most animals the mammary gland adjusts itself to the needs of the growing young. With the vigorous suckling of the newborn, milk secretion increases at a pace to satisfy the demands of rapid growth. As the young approach the weaning age and stray far enough from the teat to make their own experiments on digestion—with the mother's food, with sawdust, or with anything else that happens to be handy—they drink less milk. And with this decrease in the pull on the breast, milk secretion in the mother begins to decline. In the rat, the period of lactation can be prolonged to two or three times its normal duration by supplying successive litters of newborn animals to substitute for those approaching weaning age. It has even been possible to initiate lactation in virgin female rats by the application of newborn young to their breasts. These interesting demonstrations in the rat are matched by equally interesting ones in the larger domestic animals. Lactation has been induced in virgin heifers, in nonpregnant dry cows, in male goats, and even in bulls by persistent stimulation of the teats. This stimulation has been effective whether arising from the suckling of young animals or manual manipulation.

The stimulus is apparently carried by the nervous system to the pituitary gland, so that the latter is entirely responsible for this unorthodox lactation just as it is for the more usual kind. If the pituitary is removed from the rat, no amount of nipple manipulation can produce milk secretion. On the other hand, even with the pituitary intact, nipple stimulation is not effective unless the nerves to the nipples are intact. This nervous mechanism originating in the sensory nerves of the nipples must be an important one among the factors responsible for the rise and fall of milk production.

In some species, however, there appears to be an additional factor—distention of the mammary gland itself. In the rat, it is reported that milk secretion is not seriously impaired by the accumulation of milk in the glands. If, for example, all of the milk ducts on one side of the body are tied with a thread (ligated) so that milk cannot be delivered from these glands, milk secretion continues not only in the glands delivering milk but also in those with ligated ducts. In the guinea pig, a similar procedure causes a drying up of the glands with ligated ducts, though milk secretion continues in the glands on the other side of the body. Likewise in the sow, dog, and goat distention of the gland of an unsuckled teat leads to the drying up of that gland while the other glands of the same animal may be in full milk. In the dairy cow, milk production declines some time after the second month even though the stimulus to the nipples is kept constant by regular milking so that milk is not allowed to accumulate in the gland. On the basis of present knowledge of the endocrines and the related processes involving the nervous system, there is no plausible explanation for this.

An inventory may again be made of the known facts regarding the secretion of milk as opposed to the conclusions, or guesses, based on these facts:

1. The ovaries are not necessary for milk secretion though they are necessary for the full development of the mammary gland.

2. The important and fundamental stimulus for milk secretion comes from the pituitary gland. In the absence of this gland milk secretion does not take place unless injections of pituitary extract are substituted for the gland.

3. When the pituitary gland is intact, it is possible to bring about some milk secretion by stimulation of the nipples. Stimulation of the nipples in the absence of the pituitary is without effect.

4. Lactation may be suppressed completely or decreased in amount by distention of the uterus. The effects are similar whether the distention is that normally occurring during pregnancy or is due to retention of membranes in the uterus after delivery or abortion or to experimental insertion of foreign material (wax).

5. It is possible to inhibit milk secretion by the administration of large amounts of estrin.

6. The occurrence of heat during lactation is accompanied by a slight but definite decrease in milk yield. Moreover, the period of recurrent heat cycles coincides in time with the period of declining milk production.

7. Removal of the ovaries during lactation does not make it possible to prevent the eventual decline in milk yield.

MILK-STIMULATING EXTRACTS FROM THE PITUITARY AND THEIR RELATION TO OTHER BODY PROCESSES

Because anterior pituitary extracts are capable of producing many effects in the animal organism—effects upon growth, sex, and metabolism— several investigators have attempted chemical separation of pituitary extracts into fractions each of which would do only one thing. A fraction has been isolated that is particularly effective in stimulating milk secretion. Injected into the normal animal it stimulates the production of milk and has little or no stimulating effect on the sex glands. That, however, is not its only effect. It is reported to stimulate body growth in mice and metabolism in pigeons, although it has little ability to stimulate other endocrine organs such as the thyroid and adrenals. This somewhat purified extract, therefore, has only a few of the properties that characterize the crude extracts of the pituitary gland. Yet it is unable to cause milk secretion in animals with the pituitary removed (hypophysectomized). This does not necessarily argue that the purified extract (prolactin or galactin) is not a true representative of the pituitary secretion responsible for milk production in the normal animal.

The effects of pituitary removal are serious and widespread. Probably no bodily process is normal after such an operation. It is not like removing a leg, an arm, or an eye, when the rest of the body is not very much affected and everything else goes on as before. In the hypophysectomized animal, nothing goes on as before. The total metabolism as measured in calories per day is reduced to about 50 percent of the normal level, so that the animal cannot keep up a normal body temperature except in heated rooms. The food and water intake decrease to about half the usual amount. The blood system is badly deranged, so that the transfer of water and salts from the blood to the tissues or through the kidneys is seriously handicapped. Of particular importance is the fact that in these experimental animals nitrogen is wasted to such an extent that protein foodstuff has much less value than in the normal animal. Finally, removing the pituitary leads to pronounced atrophy or wasting away of every endocrine gland in the body. In brief, when the pituitary is removed there is not much left. It is therefore no reflection upon purified prolactin that it is unable to produce milk in the hypophysectomized animal.

Nevertheless, the failure of purified prolactin in the hypophysectomized animal must be explained. The ovary has already been eliminated as an important factor in milk secretion, so that ovarian atrophy cannot be blamed for the failure. Nor can great importance be attached to the wasting of the thyroid, although thyroid medication is able to stimulate milk production in the declining phase of lactation. Irrespective of the interest of this observation, it must be remembered that complete removal of the thyroid does not prevent milk secretion, in fact, does not even depress it very much. Complete removal of the adrenal glands, however, greatly depresses milk secretion or abolishes it completely. It might be suspected, therefore, that the failure of purified prolactin in the hypophysectomized animal is due to the wasting of the adrenal tissue. Such a suspicion is well supported by some recent experiments on the guinea pig. After removal of the pituitary, purified prolactin is able to induce milk secretion in this animal if adrenal extracts are injected simultaneously. Adrenal extracts alone are not able to induce milk secretion, even in the normal animal, but they do enable the prolactin to work in the animal without its pituitary. Thyroid extracts cannot be substituted for adrenal material in this experiment, as might be expected.

The question now arises, Are the adrenals directly involved in the process of lactation? This may be a matter of definition. Perhaps it depends upon where the line is drawn. Although the experiment has not yet been reported, it is probably safe to predict that purified prolactin would not be very effective in animals from which the heart and both lungs had been removed. There is no doubt that the heart and lungs are indispensable for milk secretion. But there is some doubt that they should be considered of any importance to milk secretion outside of their importance for the maintenance of the general health and well-being of the animal. In a like manner the adrenals are important. After removal of the adrenal glands the disturbances in the circulation and in the transfer of water and salts to and from the blood are so great that the animal cannot survive unless prompt and vigorous treatment is given. The life of such an animal can be saved either by the administration of adrenal extracts or by abundant doses of common table salt. A high intake of common salt enables the animal to compensate for its handicap to a considerable degree. It is worthy of emphasis that the simultaneous injection of common salt enables prolactin to induce milk secretion in hypophysectomized animals. In other words, purified prolactin plus common table salt is just about as effective a combination as prolactin plus adrenal extract. Consequently there is every reason to question the alleged importance of the adrenal glands for the process of milk secretion.

If it is now admitted (purely for the sake of discussion) that purified prolactin is a chemical compound that is fully capable of providing the essential stimulus for milk secretion, there still may be some doubt that it is poured out of the pituitary gland as an individual, distinct hormone during lactation. It is quite possible that instead of secreting a compound that acts exclusively on the process of milk secretion, the pituitary actually secretes a hormonal complex, containing the equivalent of prolactin, which is able to do several things at the same time.

Such a pattern of glandular activity is suggested by several examples of interrelated processes. For instance, during pregnancy there is not only an alteration in the ovaries attributable to a change in the secretion of the pituitary hormone that stimulates the ovaries (gonad-stimulating), but there are also other alterations that might reasonably be charged to the pituitary gland. Thus growth in the rat is accelerated during pregnancy and lactation, so that bred females grow faster than virgins. Since some acceleration of growth occurs during pseudopregnancy, the contents of the pregnant uterus cannot be given credit for this effect. Part of this increase in growth rate is undoubtedly due to the increased food intake, which appears as early as 48 hours after coitus. It will be recalled that growth is just as intimately related to the pituitary as is lactation or reproduction, and that no growth is possible in the absence of the pituitary. This correlation of changes in the reproductive tract with changes in the growth rate suggests a correlated alteration in the secretion of the gonad-stimulating and the growth-stimulating hormones. Another example of this same type is seen in pregnant women, who frequently show a characteristic coarsening of the facial features typical of the action of the growth hormone acting on the adult individual.

If such diverse processes as growth and reproduction are really correlated by an integration of pituitary secretions, a much closer correlation might reasonably be expected between bodily processes that are more intimately bound together—specifically, general body metabolism, growth, and lactation. At the present time no statement can be made as to whether or not such a correlation in pituitary secretions is anything more than an idea. But it would be folly to dismiss the idea without careful examination.

THE POSSIBLE RELATION BETWEEN DIET AND PITUITARY FUNCTION

Even when the pituitary gland is intact, deficiencies in the diet produce severe changes in growth, reproduction, and lactation. In part, these changes may be due to the decreased supply of raw materials out of which new tissue or milk is made. However, the pituitary secretions are themselves proteins, and it is altogether possible that adequate dietary protein is essential for the formation of the pituitary hormones. Such a situation might explain the dramatic effects on growth, reproduction, and lactation of increasing or decreasing the dietary protein.

In the last few years, several investigators have extracted from plant sources active products that stimulate the ovaries of animals into which they are injected in a manner much like that of the pituitary gonad-stimulating hormone. The active extracts have been prepared from the green leaves of young alfalfa, oat grass, and soybean plants, and from brewers' grains. It is still too early to say whether such discoveries will prove to be of significance from the standpoint of nutrition. They may, however, eventually provide an explanation for the often observed stimulating effect of young pasture grass on milk production. They may also lead the way to a new point of view in regard to the wisdom and efficacy of our present methods of curing and storing pasture grasses. In any event, without hoping too much for the future, it is to our interest to watch critically the development of such experimentation.

REFERENCES TO LITERATURE

For those interested in further reading on the topics that have been covered in this article, the following references, which will be found in Literature Cited (p. 1075), are recommended: General discussion of the endocrine glands in lactation (*334*, *425*, *844*, *1072*, *1073*[2]); effect of estrus on milk yield (*224*, *710*); effect of estrin on milk yield (*367*, *379*); influence of the nervous system on lactation (*1025*); effects of pituitary extracts on milk secretion, growth, and metabolism (*66*, *366*, *368*, *746*, *965*, *966*, *1207*); material concerning the induction of lactation by means of pituitary extracts in animals from which the pituitary glands have been removed, and the relation of the adrenals to lactation (*845*).

BLOOD CONSTITUENTS

by C. A. Cary[3]

MILK has some characteristic constituents that are synthesized in the mammary gland itself. Among these are its principal protein, casein; the milk sugar, lactose; and the characteristic volatile or easily evaporated fatty acids of milk fat. This section deals with the materials in the blood used by the gland in making these constituents. The experimental work leading up to the present knowledge of this subject has been done with goats and cows, but essentially the same results would be obtained with other mammals.

WHERE DOES MILK SUGAR COME FROM?

The sugar in blood is glucose. To convert this to the milk sugar, lactose, would require a complex and far-reaching rearrangement of the atoms in half of the molecules used in the process. Is glucose thus used by the mammary gland to make lactose? Kaufmann and Magne in 1906 (*609*) first undertook to solve this problem. They determined the amount of sugar in samples of blood taken simultaneously from the jugular vein and mammary veins of milking cows. They assumed that the samples from the jugular vein represented the composition of blood going to the mammary gland, and those from the mammary veins represented the composition of blood coming from the mammary gland. They found less glucose in the blood coming from the gland, which would indicate that some was used in the gland.

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[2] Also TURNER, C. W. THE PHYSIOLOGY AND BIOCHEMISTRY OF MILK SECRETION. Mo. Col. Agr. Pub. (unnumbered), 252 pp., illus. 1933. [Mimeographed.]

[3] C. A. Cary is Senior Chemist, Division of Nutrition and Physiology, Bureau of Dairy Industry.

Since that time workers at the Hannah Research Institute in Dairying in Scotland have shown (*125*) that blood from the jugular vein in the neck of the cow cannot be taken to represent the composition of the arterial blood going to the mammary gland. They (*126*) and a number of other workers since, have repeated Kaufmann and Magne's experiment, using arterial blood instead of jugular vein blood. The findings leave no doubt that glucose is taken out of the blood by the mammary gland. In addition, it has been shown that cultures of mammary gland tissue readily make lactose if supplied with glucose.

Recently Graham and coworkers (*429*), working formerly at Reading, England, and later at the University of Missouri, have developed a technique whereby they can measure quite accurately the rate of blood flow through the mammary gland of the goat. At the same time they are able to analyze samples of the blood going to and coming from this gland and to determine the amount of milk secreted by it. Using this unique procedure, these workers have reported that not enough glucose is taken out of the blood to make all of the lactose secreted in the milk. They conclude that both glucose and lactic acid, which may be derived from glucose, are taken out of the blood by the mammary gland and used to make milk sugar.

The secretion of lactose can be altered by altering the level of glucose in the blood. This has been done experimentally by depressing the level of glucose in the blood drastically by the administration of such agents as insulin or phloridzin. But when an attempt is made to alter the level of glucose in the blood by greatly reducing the amount of carbohydrate in the ration, the concentration of lactose in the milk is unchanged. The most pronounced changes, as a result of an abrupt and decided cut in the carbohydrate in the diet of a milking cow, are (1) a considerable drop in the amino acids in the blood, (2) a drop in milk yield, and (3) a drop in the concentration of protein in the milk but not in the concentration of lactose. The demand for material to supply energy to the organism apparently leads to the destruction of amino acids essential for the secretion of milk and for the synthesis of milk protein when too little energy is given in the ration.

WHERE DOES MILK PROTEIN COME FROM?

There are several proteins in milk. One, lactoglobulin, is present in cows' milk generally in very small amounts. It is considered identical with a globulin in blood serum (serum globulin) and is believed to be derived from that source. Lactalbumin, another milk protein, constitutes about 18 percent of the protein in cows' milk. It resembles, but is not identical with, the albumin in blood serum and is therefore considered to be synthesized by the mammary gland. Casein, the principal protein in milk, is also considered to be synthesized by the mammary gland.

In digestion, proteins are broken down into simple nitrogenous compounds known as amino acids. These are present in the blood along with polypeptides, which are simple combinations of amino acids. The amino acids and polypeptides are the building stones used by the body to build its own proteins.

Some years ago an experiment like that of Kaufmann and Magne's, described above, was tried in the laboratory of the Bureau of Dairy Industry (*195*) at Beltsville, Md., to determine whether the amino acids in cows' blood are used by the mammary gland in the synthesis of milk proteins. This work was also repeated by workers (*123*) at the Hannah Research Institute in Dairying in Scotland, and by others. There is no doubt that the mammary gland takes amino acids and simple polypeptides out of the blood, and most workers have been convinced, therefore, that these are the raw material used for the synthesis of milk proteins. Recently Graham and his co-workers (*431*) have also applied their particular technique to this problem. They report that the amount of amino acids and simple polypeptides taken out of the blood by the mammary gland of the goat does not account for the amount of protein in the milk secreted; that material of this sort is destroyed in the mammary gland; that some urea—a product of this destruction—is returned to the blood leaving the gland; and finally that serum globulin is taken out of the blood and used by the mammary gland along with some of the amino acids and simple polypeptides in the synthesis of milk proteins.

Undoubtedly amino acids and polypeptides are used in this synthesis. The evidence regarding the role of serum globulin in this connection will undoubtedly require further study. It, too, is made ultimately from amino acids, and it does, of course, get into the colostrum in large amounts.

It has already been noted that considerable reductions in the amount of carbohydrate in the diet may reduce the total amount of amino acids in the blood. This in fact is the most effective way to produce this change in the blood, and, as has been pointed out, it is accompanied by a reduction in milk yield and in the concentration of protein in the milk. Abrupt changes in either the kind or quantity of protein in the diet may also lead to immediate changes in milk yield and to corresponding changes in the concentrations of both the protein and the fat in the milk. Sometimes, when the dietary protein, the milk yield, and the concentrations of protein and fat in the milk are thus reduced, the total amount of amino acids in the blood may not be demonstrably altered; but certain essential amino acids in the blood may vary under these conditions quite independently of the total.

Not always are changes in dietary protein directly reflected in the yield and composition of the milk even at levels of feeding inadequate for continued production. A cow's capacity to store protein or to supply protein from bodily reserves may act to maintain the yield and composition of the milk and thus obscure, for long periods of time, inadequacies in the diet.

It is possible that the total effect of a change of dietary protein should not be considered as brought about entirely by a change in the supply of raw material for the synthesis of milk protein. Such changes in the diet and blood may alter the formation or function of hormones, enzymes, or other factors, which also directly or indirectly affect the secretion of milk.

A change in the quality or quantity of protein in the diet may, as noted, not only affect the secretion of milk protein, but alter the secretion of milk as a whole—that is, of all of the constituents of milk.

How such a complex change in milk secretion may follow so relatively simple a change in ration is definitely unknown, although hypotheses to account for such correlations in elaboration of the constituents of various glandular secretions have often been suggested.

WHERE DOES MILK FAT COME FROM?

It is true that the composition of milk fat may be altered by altering the kind of fat fed, indicating that fatty acids may pass unchanged in character from the feed into the milk. With the exception of the volatile fatty acids, all the fatty acids in milk fat, so far as is known, could be derived directly from the feed and from the blood.

Fatty acids occur in the blood in several combinations—as ordinary fats (glycerides), as compounds containing phosphorus (phosphatids), and as esters or compound ethers of cholesterol, a fatty alcohol found in animal tissues. As a result of work done in the Bureau of Dairy Industry (*777*) at Beltsville, it was thought that the fatty acids in milk fat were derived from the phosphatids in the blood; but the workers in the Hannah Research Institute in Dairying (*124*) in Scotland later investigated this question with improved methods and were unable to confirm this view. More recently Lintzel (*689*), Graham and collaborators (*430*), Maynard and collaborators (*771*), and Shaw and Peterson (*1033*) have shown that the fatty acids used in milk secretion are not derived from either phosphatids or cholesterol esters, and therefore presumably come from the ordinary fats (glycerides) in the blood. This, of course, does not account for the volatile fatty acids that are made in the gland itself, and no satisfactory work throws any light upon their origin.

Graham (*429*) in his work has also observed that the increase in the volume of carbon dioxide in the blood leaving the mammary gland is greater than the volume of the oxygen taken out of the blood by the gland. Such a condition with an animal has generally been interpreted to mean that carbohydrate is being converted into fat because this process would lead to the evolution of carbon dioxide without a corresponding utilization of oxygen. Whether fat is thus being formed in the mammary gland in addition to being taken from the blood is not definitely known. A considerable portion of milk fat is undoubtedly made from carbohydrate, this transformation probably occurring largely elsewhere in the body.

Maynard (*770*), at Cornell University, has made an extensive study of the relation between the concentration of fat in milk and the concentration of lipid (total fatty materials) in blood. There was no correlation, although when the fat content of the diet is below a certain level, milk yield is depressed; but Maynard does present an interesting set of curves (*770*) showing a decline in the concentration of fatty materials in the blood parallel with the decline in milk yield that occurs with the advance in lactation. The significance of this observation is not clear.

As already pointed out, when the amount of protein in the diet is drastically changed and the milk yield is thereby altered, the concentration of fat and protein in the milk is also altered. In an experiment in the Bureau of Dairy Industry the fat dropped from an average of 4.8 percent in one lactation to 3.3 percent in another as a result of inadequate protein feeding. When a decided reduction in milk yield is effected, however, by a change in the total energy (carbohydrate) content of the diet, the concentration of fat shows a tendency to increase with a drop in milk yield, and vice versa. In general the average concentration of protein in milk bears a fairly constant relation to that of the fat; and both may be maintained at what may be considered a normal level in milk for long periods even on diets that may finally prove inadequate in protein to maintain production.

For references to the original literature on the blood precursors of milk constituents, the reader is referred to bibliographies in papers by Graham and others (*429*, *431*) and the bulletin by Maynard and others (*771*); and for the literature on the relation between diet, composition of the blood, and secretion of milk, to the article by Maynard and others (*770*) and the paper by Cary and Meigs (*197*).

MILK IN NUTRITIONAL RESEARCH—A SKETCH OF PROGRESS

by C. A. Cary [1]

THIS article ostensibly deals with milk, but actually it has a much wider interest. Without attempting any formal history, the author gives some revealing glimpses of the way modern knowledge of nutrition has developed in laboratories all over the world. It is background material for those interested in either animal or human nutrition.

KNOWLEDGE of the composition of milk, particularly of the vitamins and some of the less plentiful minerals found in it, has resulted largely from a study of its nutritional value. The story is a long one and this article is intended merely to suggest how some of this knowledge has been gained.

DISCOVERING THE EXISTENCE OF UNKNOWN FACTORS IN MILK

About 1873, one of the important problems in Voit's laboratory in Germany was to determine whether or not a constant supply of mineral salts, like those in milk, is necessary in considerable quantity for the nutrition of adult animals; and Forster, in that laboratory, concluded that the full-grown animal does require considerable quantities of these inorganic salts. The eating of food from which they were removed appeared even more rapidly fatal than the deprivation of all food, according to Forster.

Bunge (*171*),[2] also in Germany, did not consider that the experimental work back of this conclusion was convincing. "In fact," he says, "it is a priori difficult to see what the constant addition of salts is required for."

However amusing this view may now seem, it was serious then; and, after showing that the salt content of the milk of a given species of animals is particularly adapted to nourish the growing young of that species, Lunin, in Bunge's laboratory, tried two crucial experiments on adult mice. In one he fed a mixture of cane sugar, milk protein, and fat. The ration was incomplete; the animals lived only 11 to 21 days. In the second experiment Lunin fed a mixture of lactose, milk protein, milk fat, and the salts of milk. This ration was also incomplete; and Bunge in his Physiologic and Pathologic Chemistry, as translated (*171*), gives the results of this often-cited experiment in the following words: "It is a noteworthy fact that, although animals can live on milk alone, yet if all of the constituents of milk which according to the present teachings of physiology are necessary for the maintenance of the organism be mixed together, the animals rapidly die." Bunge then puts this question, "Does milk contain, in addition to protein, fat, and carbohydrates, other organic substances which are also indispensable to the maintenance of life?"

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[2] Italic numbers in parentheses refer to Literature Cited, p. 1075.

The necessity of these salts in adult nutrition was finally definitely determined, but Bunge's text with this question in it was still in use in English and German universities when, about 25 years later (1906), Hopkins, who worked in the laboratory at the University of Cambridge, England, similarly announced: "But, further no animal can live upon a mixture of pure proteins, fats, and carbohydrates, and even when the necessary inorganic material is carefully supplied, the animal still cannot live." With this pronouncement Hopkins presented the curves in figure 1 (*538*), which show the growth of rats on the mixture of the then known nutrients in milk, and upon these nutrients plus a little whole milk. In this work Hopkins showed emphatically the existence of unknown essentials in normal nutrition.

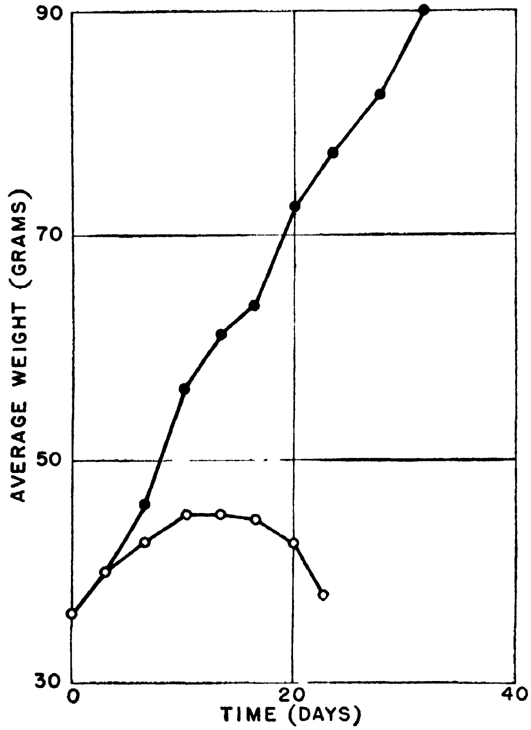

Figure 1.—Growth of rats on an artificial diet containing the known constituents of milk, with and without the addition of natural milk. The lower curve shows the average weight at different ages of six rats on the artificial diet alone; the upper curve, that of six similar animals receiving in addition 2 cubic centimeters of milk each per day.

As the list of known nutrients in milk has increased from time to time, this same comparison, using all the known constituents in one case and milk itself in the other, has been repeated—and probably will be repeated—time and again; and each time it has demonstrated that there were still unknown factors affecting the growth, health, or reproduction of the experimental animals. This is particularly true of the vitamins. Hopkins recently (1937) said (*537*):

> I am myself sometimes spoken of as the discoverer of the vitamins, but that is a title that I cannot justly claim . . . Perhaps I was the first to emphasize

their physiological and universal importance in nutrition as distinct from certain of their more special pathological relations.

DEFICIENCY DISEASES POINT THE WAY TO FINDING THE VITAMINS

This quotation from Hopkins leads to another, slightly older channel of information that has already contributed much during this century to the knowledge of nutrition and of the composition and nutritive value of milk—the study of what are now known as nutritional-deficiency diseases. Probably not long after man became sufficiently civilized to have these diseases he began tampering with his diet to cure them; but progress was slow. Funk (*402*) said some years ago regarding the contribution of the study of deficiency diseases to knowledge of nutrition:

> In spite of the great powers of observation possessed by such investigators as Bunge and Hopkins, the conception of the vitamin theory could never have attained its present importance if a powerful impulse had not been received from clinical sources.

VITAMIN B_1

The record indicates that beriberi, the disease caused by a deficiency of the recently (1936) synthesized vitamin B_1 in the diet, was recognized by the Chinese as early as 2697 B. C. (*1229*). Apparently it was unknown to physicians of the western world until A. D. 1645; and little was done to determine its cause until in 1885 the Japanese felt the urge to preserve the health of their developing navy. Then Takaki, as has frequently been noted, altered the diet of the Japanese sailors in several ways, mainly by substituting barley for polished rice—previously the chief article of their food—and the occurrence of beriberi, which had been officially reported as annually affecting 25 to 40 percent of the entire naval force, became negligible.

Progress after this was very rapid, and its rapidity and thoroughness attest the relative effectiveness of modern research methods. The dietary deficiency causing beriberi was further confirmed. All sorts of foods were tested out for their antiberiberi or antineuritic properties—the main symptoms of beriberi being a nerve disease, polyneuritis. Rough methods were devised for measuring the potency of these preventive foods with rats, with pigeons, and with other birds that are readily susceptible to polyneuritis.

It was found that the foods that contained the beriberi-preventive vitamin also invariably promoted the growth of rats when added to such artificial mixtures of known dietary essentials as those used by Lunin (*171*) and Hopkins (*538*). The same was true of all water extracts of these foods, and many workers assumed, without very good evidence, that the antiberiberi vitamin and this growth-promoting material found with it were one and the same substance. As a result, the effect of foods on the growth of rats was used as a measure of their content of the beriberi-preventive vitamin.

In 1926, Jansen and Donath (*581*, *582*, *583*) isolated the active antiberiberi principle itself in crystalline form; and in 1936, some 4,600 years after the first description of beriberi in known literature, this curative principle was prepared synthetically by Williams and Kline in this country. This antiberiberi or antineuritic vitamin is now known as vitamin B or vitamin B_1. It is also called by the chemical name of thiamin.

VITAMINS A, D, AND C

The history of other dietary diseases is much the same. It is said (*303*) that Hippocrates recognized hemeralopia and described a cure for it that contained vitamin A; yet the fact that the vitamin A potency of plant foods is due to the pigment carotene was not clearly demonstrated until 1928–29 by Von Euler and collaborators (*338*), and by Moore (*807, 808, 809, 810*); and the two outstanding events in the work reported on this vitamin in 1937 were its synthesis in Kuhn's laboratory in Heidelberg, Germany, and its isolation in crystalline form from a natural source by Holmes and Corbet at Oberlin College in Ohio.

With the D vitamins, which are involved in the prevention and cure of rickets, and with vitamin C (ascorbic acid), which prevents or cures scurvy, the situation is much the same as with vitamin B_1 and vitamin A.

THE SEARCH FOR THE PELLAGRA-PREVENTIVE FACTOR

The studies of human pellagra are of particular interest in illustrating how knowledge of the composition of milk and other foods has developed. The assumption that the antiberiberi and the rat growth-promoting properties of foods were due to one and the same substance was a bad mistake. Such leaders in the field as Eijkman and collaborators (*314*) and Jansen (*580*) declared against this assumption at the time; but it was not until 1926 that the fallacy was clearly demonstrated. It had been shown that the antiberiberi vitamin is destroyed by heating with steam in a closed vessel (autoclave) at 15 pounds pressure for 6 hours; and Smith and Hendrick (*1082*) in the United States Public Health Service then showed that yeast, autoclaved in this way, still had pronounced growth-promoting properties when fed to rats. There was thus shown to be, besides the antiberiberi vitamin, which itself does promote growth, another growth factor that was more stable to heat. This heat-stable fraction also prevented blacktongue in dogs, which is analogous to human pellagra.

This discovery added zest to the efforts to isolate the heat-stable growth-promoting factor. Milk and eggs contain it and are pellagra preventives. In 1933 Kuhn and his collaborators at Heidelberg isolated from this heat-stable fraction in milk and egg white what is now known as vitamin B_2 or riboflavin. Its chemical structure was later determined, and it was prepared synthetically.

But with certain basal diets pure riboflavin did not have the growth-promoting properties of the entire heat-stable fraction from yeast and did not prevent pellagra; and when riboflavin was used in place of this fraction in the diet, the rats developed a characteristic skin disease or dermatitis. Evidently another factor in this yeast fraction was involved. The material a deficiency of which produces the characteristic dermatitis in rats was isolated in crystalline form in this country by Keresztesy and Stevens of Merck & Co. in February 1938; in Heidelberg, Germany, by Kuhn and Wendt in April 1938; and at the University of California by Lepkovsky in February 1938. Its chemical structure has recently (February 1939) been determined by Kuhn and Wendt in Germany; and, on March 5, 1939, workers in the laboratory of Merck & Co. in this country announced its chemical synthesis (*483*). It has been called vitamin B_6, adermin, and factor 1 by various workers.

But vitamin B_6 was still not the pellagra-preventive factor in yeast, eggs, milk, and other foods. A peculiar situation was discovered. In his book on the vitamins (*402*), Funk, who gave us in quite elaborrate form the vitamin theory of disease and the original class name for the vitamins, had described his efforts to isolate the antiberiberi vitamin from rice bran and yeast. He had isolated, among other things, nicotinic acid. According to Funk, this acid was first found in nature by Suzuki and associates in 1912, the year before his own isolation of it. When he tested it for antiberiberi properties, nicotinic acid was ineffective.

Nicotinic acid was therefore known to occur in yeast, and it was heat-stable like the pellagra-preventive factor. In 1937 Elvehjem, Madden, Strong, and Woolley (*327*) at the University of Wisconsin gave it to dogs suffering with blacktongue. They say, "A single dose of * * * nicotinic acid gave a phenomenal response. * * * The appetite improved immediately," and upon "further additions of the nicotinic acid growth continued uninterruptedly." Fouts, Helmer, Lepkovsky, and Jukes (*380*), in California in November 1937, report trying nicotinic acid on four persons suffering from pellagra. The effect was remarkable: "All patients showed distinct improvement in general condition and mental attitude within 48 hours of onset of therapy," and other symptoms of the disease were definitely ameliorated. Nicotinic acid, according to Williams and Spies (*1229*), is "at least to an astounding degree, curative for human pellagra"; but it is "perhaps not the sole pellagra vitamin."

VITAMINS THAT HAVE BEEN DEFINITELY DETERMINED AND SYNTHESIZED

Thus from the original vitamin B complex there have now been prepared in pure crystalline form the following vitamins of which the chemical structure is known and the chemical synthesis of which has been accomplished: From the heat-labile (unstable) fraction—vitamin B (or vitamin B_1 or thiamin); from the heat-stable fraction—nicotinic acid, vitamin B_2 (or riboflavin), and vitamin B_6 (or adermin or factor 1).

In addition to these vitamins, which have been isolated in pure chemical form from what was originally known as vitamin B, the following vitamins have also been isolated in pure form and their chemical nature has been definitely determined: Vitamin A and at least four plant carotinoids that are precursors of vitamin A (there may be more than one vitamin A, but only one has been definitely identified); vitamin C (ascorbic acid or cevitamic acid); vitamin D, the antirachitic vitamin (at least two D vitamins have been isolated and identified chemically); and vitamin E.

The number of these definitely known vitamins has been constantly and rapidly increasing, and undoubtedly others occur in milk.

NUTRITIONAL DEFICIENCIES IN MILK AS A SOURCE OF KNOWLEDGE

Information about milk has also resulted from studying its nutritional deficiencies. Between 40 and 50 years ago Bunge (1891) and

Häusermann (1897) in Bunge's laboratory published data on various plant and animal materials that showed that cow's milk, human milk, and dog's milk are all very poor sources of iron. The mineral content of the newborn puppy was compared with that of dog's milk. "With the exception of the iron, the relative proportion of the remaining constituents in the ash is almost identical" in the milk and the newborn, Bunge said (*171*); but the iron in the milk "is six times less than that in the ash of the suckling animal." However, the iron in young dogs, cats, and rabbits was highest at birth: "At least five times more iron is found in the liver of the new-born than in that of full grown animals." Bunge added:

> The amount [of iron] which must be conveyed to the infant organism can reach it in two ways: through the placenta and through the mammary glands. * * * But if it reaches the fetus through the placenta, its safety is assured.

Nature evidently offsets the iron deficiency in the milk by depositing stores of iron in the fetus. With newborn animals that, like the guinea pig, "begin by eating vegetable food from the first day, and select by preference the leaves that are very rich in iron," this storage of iron is negligible and milk itself plays a subordinate part in supplying the iron requirements; but with other animals, like the rabbit, the newborn may contain three or four times as much iron per 100 grams of body weight as the adult animals.

How long will these stores of iron last the growing animal? Bunge concluded that "nature herself has made an experimentum crucis" (*171*), and that the amount of iron in the body of the newborn is adapted to its dietary instincts, or its dietary instincts are adapted to the amount of iron, so that by the time the bodily store is exhausted, the animal is eating food richer than milk in its content of iron. He wrote:

> The animals at this time already appear to be anemic, [and] if the attempt were made to feed the young animals exclusively with milk after the period of suckling had elapsed, they would certainly become anemic.

Häusermann tried to supplement milk in various ways to overcome this nutritional anemia in older animals (see Bunge (*171*)). The question of utilizing inorganic iron salts to overcome it was not definitely settled, however, until Hart, Steenbock, Waddell, and Elvehjem (*493*), at the University of Wisconsin, showed in 1928 that copper as well as iron is necessary to prevent this nutritional anemia.

Milk is also deficient in copper; and there is evidence, as with iron, that the newborn is prepared to meet this deficiency in its mother's milk, and that many foods may readily be selected to meet the later needs of the animal for copper.

Copper has a widespread occurrence as an impurity in the salts of many metals, and shortly after the discovery of this function of copper by Hart et al., many of these salts were tested for their effect on nutritional anemia and found to be effective in curing it; but according to Elvehjem (*323*) all of these statements indicating the effectiveness of salts other than copper and iron in nutritional anemia "have been retracted or refuted in more recent papers." Rats have been kept on a ration of milk, iron, and copper for 667 days without developing nutritional anemia.

Although, in this work, manganese was found to have nothing to do with the development of nutritional anemia, it was found to affect growth. Workers at the University of Wisconsin, using mice and rats, "demonstrated that the addition of traces of manganese to a diet of whole cow's milk supplemented with iron and copper has a favorable effect on growth," and that "rats on cow's milk mineralized with iron, copper, and manganese made average daily gains very similar to those made by rats on an ordinary ration." The manganese content of milk is very low and is not affected by the diet of the lactating animal; but the requirements of young animals must also be very low as the manganese requirement of the young growing pig is satisfied by a concentration of 1 part of manganese in 180,000 of its ration. The relationship of manganese to reproduction is discussed elsewhere in this Yearbook (p. 488). Sherman (*1048*) says:

> It is still an open question * * * whether one is likely ever to meet a case of manganese deficiency except when deliberately induced by artificial procedures.

ARE THERE MORE VITAMINS?

Thus studies of the nutritional deficiencies of simplified diets, of the use of milk in deficiency diseases, and of the nutritional deficiencies in milk itself have added much to practical knowledge of the nutritional value of milk. But it is obvious that this knowledge is very rapidly changing and still incomplete, and that it must constantly be reappraised in the light of more recent developments.

In January 1939, Oleson, Bird, Elvehjem, and Hart (*872*) at the University of Wisconsin reported as follows, in very much the same vein as Lunin in 1881 and Hopkins in 1906:

> When rats are placed on purified diets low in the vitamin B complex but supplemented with thiamin, riboflavin, nicotinic acid, and concentrates or crystals of vitamin B_6, very poor growth results. It is evident that other factors are needed.

And again: "It is possible that several factors are concerned. In fact the evidence points to this conclusion." A review, The B-Vitamins Except B_1 and the Flavins, has recently been published by Elvehjem (*324*).

Biological methods are never precise, and their accuracy varies with knowledge of the factors and conditions involved. As information regarding the physical and chemical properties of the vitamins has developed, chemical and physicochemical methods for assaying them have in some instances been devised; but these, although more precise than the biological methods, frequently yield results of yet undetermined accuracy and value. This condition is improving very rapidly; but in assigning vitamin values to milk one must pick his way amid an array of data that is very confusing in some instances and very incomplete in others.

NUTRITIVE REQUIREMENTS OF SWINE

by N. R. Ellis and J. H. Zeller[1]

THIS article deals with the more technical aspects of swine feeding, outlining results of some of the research work that has been done on the requirements of the pig for energy, protein, minerals, and vitamins. The practical feeding of hogs, based on these requirements, is considered in a later article.

THE HOG excels other livestock as an economical converter of feed into body tissue, the products of which are largely meat and fat. Fundamentally, the nutritive requirements of swine are not so complicated as those of other classes of livestock. The swine ration is largely made up of concentrated feeds with only a small proportion of roughage, aside from good pasture. Hogs grow rapidly and most of them reach market weight at 7 to 10 months of age. They also reproduce at a much younger age than most farm animals. Well-developed gilts are usually bred to farrow their first litters at approximately 1 year of age.

The growth of swine follows the same general law as that of other animals, but they grow much faster in proportion to their body weight than the larger farm animals. Growth curves showing the rate of increase have been published by various investigators. The curves given in figure 1 show a somewhat faster rate than most of the other United States data. These curves are based on records kept on litters used in record-of-performance tests at the Agricultural Research Center, Beltsville, Md., for the autumn farrows of 1936 and 1937 and the spring farrows of 1937 and 1938. The sows and the pigs of all four farrows were handled under essentially identical conditions except for the differences due to season of the year. Besides the ration of yellow corn and a protein mixture with mineral supplements incorporated, the sows grazed on rye pasture. The pigs were weaned either at 8 or at 10 weeks and a large proportion were placed on the record-of-performance test. For the most part, the animals were removed from the feed lot when they attained a weight of approximately 225 pounds. The pigs were self-fed whole yellow corn and a mixture (known as the trinity mixture) of 50 parts tankage, 25 parts linseed meal, and 25 parts alfalfa-leaf meal, plus 5 parts of a mineral mixture composed of 50 parts ground limestone, 27.97 parts steamed bonemeal, 20 parts common salt, 2 parts iron oxide, 0.01 part copper sulfate, and 0.02 part potassium iodide. The average birth weight of 1,377 pigs was 2.91 pounds.

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Because of the divergence in rate of growth between fall- and spring-farrowed pigs, separate growth curves are shown for the two groups. It will be noted that the average weight of the fall pigs (fig. 2) at the age of 22 weeks was approximately 145 pounds and of the spring pigs, 130 pounds. This difference of 15 pounds was probably associated with temperature. The hot summer months were apparently not so conducive to growth as the cool fall months. Beyond the age of 22 weeks the growth rates were approximately parallel. During the last 8 weeks the growth rate averaged 1.65 pounds a day. Further reference to the feed consumption of record-of-performance pigs will be found elsewhere in this article.

COMPOSITION OF THE PIG'S BODY

In studying the nutritional needs of the pig it is well to consider first the percentage composition of the body. Some figures based on analyses made at the Agricultural Research Center are shown in table 1. These percentages are subject to wide variations owing to

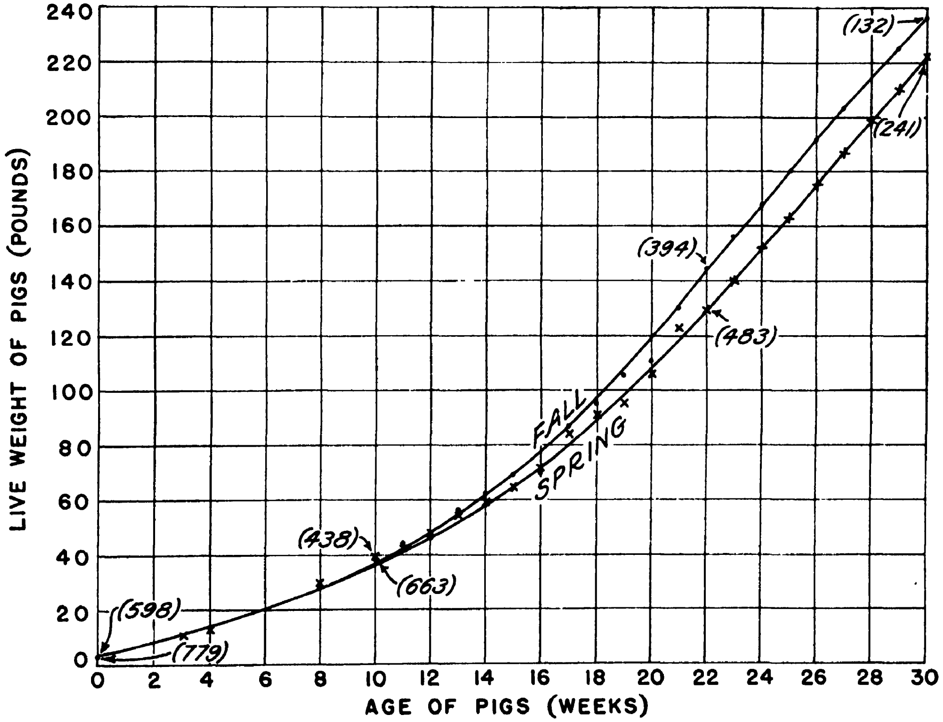

Figure 1.—Increase in live weight of pigs in 30 weeks, based on averages of numbers of pigs shown in parentheses.

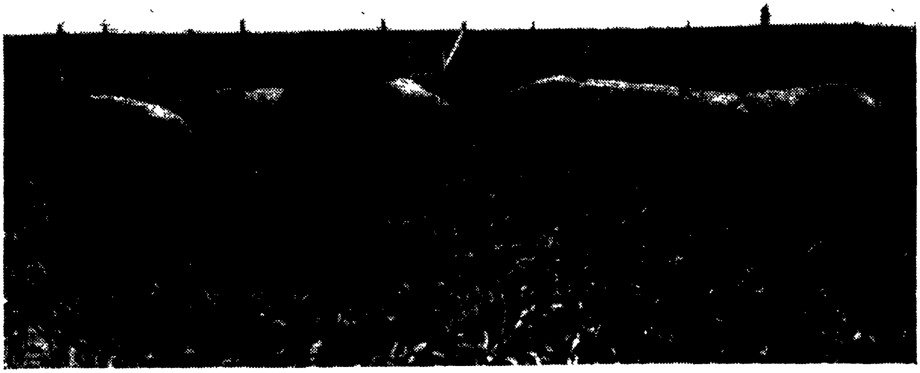

Figure 2.—Fall-farrowed pigs grazing on rye pasture.

differences in type, age, and nutritional condition. They do, however, show the general trend as the pig grows and fattens. Water is an essential constituent of the body, found in the largest amounts in the blood and muscle tissues and constituting 40 to 45 percent of the weight of the average 225-pound market hog. The percentage of protein, which is found in every cell of the muscles, tendons, and soft tissues, is highest in the young animal and decreases as the pig fattens. The percentage of fat increases as the pig fattens. Because of the small skeleton of the pig the percentage of mineral matter is small and does not vary widely.

Table 1.—*Body composition of swine*

Condition of fatness	Weight at slaughter	Body substance	Components of body substance			
			Water	Protein	Fat	Ash
	Pounds	*Pounds*	*Percent*	*Percent*	*Percent*	*Percent*
Thin	106	100	56.3	14.9	25.8	3.1
Moderately fat	162	154	49.2	13.7	34.2	2.9
Fat	219	210	44.3	12.6	40.6	2.5
Very fat	230	219	41.4	10.5	45.9	2.3
Extremely fat	343	327	37.7	10.8	49.5	2.1

REQUIREMENTS FOR ESSENTIAL NUTRIENTS

Problems relating to the nutritive requirements of swine, along with those of other farm animals, have engaged the attention of scientific investigators since the middle of the nineteenth century. The classical experiments of Lawes and Gilbert (*665*)[2] at the Rothamsted Experiment Station in England, on the composition of the body increase of swine in relation to the composition of the feed ingested have been cited many times by nutrition workers in the past 80 years. Among other findings, this work formed an important and incontrovertible link in the evidence that body fat is formed from the carbohydrate as well as the fat in foods.

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[2] Italic numbers in parentheses refer to Literature Cited, p. 1075.

During the third quarter of the last century, the concept was firmly established that the fundamental nutritive needs of the animal body were primarily for energy, with enough protein for maintenance and the building of muscle tissue. Much of the early work on feed requirements was done by German investigators. The feeding standards formulated by Wolff, which have come down to the present day in various modifications, was first published in 1864 (*32, p. 689*). These standards listed the amount of digestible crude protein, carbohydrates, and fat required daily by the different classes of farm animals, including swine.

The idea that energy and protein were the only essentials to be considered in feed requirements persisted well into the present century. Indeed, Armsby, who was responsible for the introduction of the German feeding standards in this country, wrote in 1912 (*31*) that "the chief function of the feed aside from a minimum of protein, is to supply energy." It is true that the need for a few mineral elements, such as the calcium and phosphorus found in bones, and sodium chloride to satisfy salt hunger, was recognized. The needs of livestock, with the possible exception of swine, for minerals were considered to be satisfied by the ordinary feeds that would meet energy requirements. The discovery that swine often needed additional mineral supplements did much to promote research on the requirements of other species and to extend inquiries to a wide range of mineral elements.

Qualitative differences in proteins were also recognized early in the present century. Corn had become the staple hog feed at an early date in this country. With the recognition of the fact that the proteins in corn are of low quality owing to the absence of certain essential amino acids, numerous hog-feeding trials demonstrated the value of various supplementary feeds rich in protein.

Early research on feed requirements was directed more to the needs of cattle and sheep, and even the horse, than to those of swine. Much of the work on swine was concerned with such questions as the relative advantages of grinding, soaking, and cooking grain, and the influence of the nutritive ratio between energy and protein on the liveweight gains and the proportion of lean to fat in the carcass. Later, when the complications of mineral essentials and protein quality came to be recognized in swine feeding, the inexactness of the various sets of standards based on quantity of energy and protein were clearly evident.

Today, the problem of fundamental nutritive requirements is broader and more complex. To the list of the more common and plentiful mineral elements such as calcium, phosphorus, potassium, sodium, magnesium, chlorine, iron, and sulfur have been added iodine, copper, manganese, cobalt, and zinc. Others are still in the doubtful class. The problem of vitamin requirements is a complex and expanding subject. The role of diet in relation to hormones is not well understood. Finally, it is more and more evident that the requirements of swine for the various essential nutrients are different from those of other farm animals.

ENERGY

Much attention has been given to the energy requirements of the animal body for maintenance. Because the pig is a fast-growing animal and the great majority of the pigs on farms are in the growing and reproductive stages, the question of maintenance of body weight is less important than it is in the case of horses and cattle, where mature animals are kept for extended periods. Nevertheless, the amount of food needed for maintenance should be evaluated as fundamental to the needs for body increase and reproduction.

One of the chief difficulties in the expression of the energy required for maintenance has been the segregation and evaluation of the portion above the basal metabolism (when the animal is completely at rest) that is expended (1) in eating, digestion, and assimilation of food, and (2) in exercise and activity. Some investigators have considered these expenditures a large, and others a small proportion of the total energy requirement. Likewise, certain of the reports show a definite allotment of energy for these secondary expenditures, while others have simply divided the total energy requirement into (1) net energy required for maintenance, and (2) energy required for body increase and reproduction. Some of these problems have been discussed by Mitchell and Kelley (*802*).

In 1917, Armsby summarized the existing information on maintenance requirements of swine (*32*) and found that the net energy needed per 100 pounds live weight was 1,199 calories a day. Since that date there have been a number of contributions. Some English breeds of swine were studied by Deighton, using a calorimeter, and from these data on castrated male and female pigs, along with additional data obtained at the Missouri Agricultural Experiment Station, Brody et al. (*157*) have derived prediction equations by means of which the basal metabolism of different weights of pigs may be calculated.[3] Brody and his coworkers have also proposed a feeding standard for total maintenance, which is twice that of their basal metabolism standard. Furthermore, they have expressed the feed requirements in terms of total digestible nutrients. Danish experiments by Breirem (*150*) on bacon-type pigs yielded a formula somewhat different from that of Brody.[4]

In Sweden, Edin and Helleday (*304*) have derived another equation from Swedish, American, German, and Russian feeding and slaughter tests for estimation of the maintenance and production requirements.

In a study of the energy and protein requirements of growing swine, Mitchell and Hamilton (*799*) found that 1 pound a day per 100 pounds live weight of a diet consisting of yellow corn, middlings, and tankage was required for maintenance of body weight in pigs weighing approximately 225 pounds, while 1.5 pounds per 100 pounds live weight was required by 60-pound pigs.

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[3] The equation for castrated male and female pigs over 50 kilograms (110 pounds) live weight is represented as $\frac{Q}{M}=34e^{-0.011\,M}+10$, where Q is the basal heat production in calories per day, M is the weight of the pig in kilograms, and e is the base of natural logarithms. Brody and coworkers have derived a general equation for relating the basal metabolism in calories to body weight for animals as a group (see the article on Factors Affecting Maintenance Nutrition, Feed Utilization, and Health of Farm Animals, p. 437). This equation, $Q=70.5\ M^{0.734}$, where Q is the basal metabolism in calories and M is the body weight, yields values generally comparable with those of the foregoing.

[4] $E=2126\,\frac{(W)}{100}\,5/9$, where E is the daily requirement of net energy and W is the live weight in kilograms.

TABLE 2.—*Comparison of different estimates of maintenance energy requirements of pigs per day*

Weight of pig (pounds)	Basal metabolism					Resting				Daily maintenance (European)		Practical maintenance
	Deighton (English)	Brody			Mitchell and Hamilton	Deighton (English)	Brody		Mitchell and Hamilton	Breirem	Edin and Helleday	Brody
		Female	Male	General			Female	Male				
	Therms [1]	*Therms*	*Therms*	*Therms*	*Therms*	*Therms*	*Therms*	*Therms*	*Therms*	*Therms*	*Therms*	*Therms*
50	1.01	0.82	0.92	0.71	1.00	1.41	1.55	1.48	1.32	0.93	1.17	1.37
100	1.33	1.34	1.50	1.16	1.80	2.25	2.47	2.40	2.37	1.37	1.98	2.28
150	1.78	1.68	1.92	1.56	2.50	2.72	3.03	3.03	3.29	1.72	2.40	3.06
200	2.05	1.91	2.24	1.93	3.00	2.96	3.31	3.40	3.95	2.01	2.47	3.79
250	2.24	2.11	2.54	2.28	3.00	3.11	3.48	3.69	3.95	2.28	----------	4.40
300	2.40	2.28	2.83	2.62	----------	3.22	3.60	3.94	----------	2.52	----------	5.07
400	2.66	2.61	3.42	3.27	----------	3.38	3.78	4.42	----------	2.96	----------	----------

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[1] A unit of heat and energy equal to 1,000 calories.

A summary of the maintenance requirements as determined or compiled by different investigators is given in table 2. As already indicated, it has not been possible to express all requirements strictly on the basis of economic maintenance or basal maintenance. Considerable variability is noted in the figures. However, they are believed to present a fair picture of the probable range under reasonably restricted environmental conditions.

The production requirements over and above maintenance must be considered from the standpoint of the product. In growing and fattening pigs, the product is largely fat and protein. Because of the increase in proportion of fatty tissue to muscular tissue with increasing weight, there is a steady increase in the energy content of each additional pound of gain. Mitchell and Kelley (*802*) have estimated the values for different weights of pigs reared according to American feeding practice. For a 75-pound pig, 1,625 calories are stored, while for a 225-pound pig 2,600 calories are stored in 1 pound of live-weight gain. The feed required to furnish these energy values have been estimated in a number of studies also cited by Mitchell and Kelley. The experiments of Mitchell and Hamilton (*799*) would indicate that 5.4 pounds of a ration of corn, tankage, and middlings would be required for a 2-pound gain in a 225-pound pig.

Pregnant gilts have a considerable amount of energy stored in body tissue as fat and protein besides the portion required for the embryos. Older sows also store a large amount of fat that is later utilized during lactation in the formation of milk. The demands of lactation for energy are much greater than those of pregnancy. It is the exception rather than the rule for a sow nursing a fair-sized litter even to maintain her weight, much less to increase it. The situation is quite comparable to that with the milking cow.

Numerous so-called energy feeding standards for swine have been proposed. For the most part they express the combined requirements for economic maintenance and production. On the one hand, economic maintenance, which includes the quota necessary to cover the normal muscular activity in addition to the energy expended in maintenance,[5] has been difficult to determine precisely, while on the other variability in production requirements and feeding practices has caused the proponents of most standards to set up values permitting a wide latitude of feed allowances.

Investigators have used several forms for expressing the energy requirements, so that there has been considerable confusion in interpreting results for the evaluation of feeds and rations. Because of its wide use over an extended period, the net energy basis has been utilized in the present discussion as the common ground upon which to compare different standards.[6] It has been found that the net energy value of a given feed varies with the body function being supported. It is higher for maintenance than for fattening. Undoubtedly the values for other functions are also different from those of either maintenance or fattening. Likewise, the energy values for different combinations of feeds are variable and are not necessarily the cumulative total of the individual components determined separately. Processing methods employed in preparation of feeds also influence the digestibility and thereby the available energy. The most exact measurements are accordingly those on a given mixture fed under well-defined conditions.

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[5] See Factors Affecting Maintenance Nutrition, Feed Utilization, and Health of Farm Animals, p. 431.

[6] Net energy is an expression of the energy of the feed actually useful for body functioning, and the net energy values are intended to show the amount of body product which may be expected from a unit weight of feed.

Table 3 gives several of the standards in abbreviated form to illustrate some of the differences encountered in them. The table also shows the changing requirements for different functions—growth, fattening, pregnancy, and lactation. In order to express the data on a comparable basis, it has been necessary in some cases to modify the figures from their original form. It will be noted that therms of net energy (a therm is 1,000 calories) are given in each of the five standards. Along with the net energy requirements are estimated amounts of feed mixture required. These are on an as-fed basis and of the type appropriate to accepted practice. The data of Mitchell and Hamilton (*799*) are based on results from swine type studies in which carcass analyses and digestibility experiments were conducted. The Fraps standard (*383*) is a tentative one based on digestion and growth data expressed in terms of production values for the more common American hog feeds.

TABLE 3.—*Comparison of standards for total daily energy requirements of swine*

Class of hogs	Mitchell and Hamilton		American practice		European practice	
	Net energy	Feed mixture	Net energy	Feed mixture	Net energy	Feed mixture
Growing and fattening pigs:	*Therms*	*Pounds*	*Therms*	*Pounds*	*Therms*	*Pounds*
50 pounds	2.18	2.6	2.40	2.9	1.89	2.5
100 pounds	3.53	4.3	4.00	4.9	3.10	4.1
150 pounds	4.89	6.0	5.50	6.6	5.04	6.7
200 pounds	6.08	7.4	6.90	8.1	6.35	8.5
250 pounds	6.33	7.7	8.30	9.7	8.12	10.8
300 pounds			9.25	10.7		
Pregnant gilt (300 pounds):						
First week			5.26	6.2	3.4	4.6
Sixteenth week			4.28	5.0		
Pregnant sow (400 pounds):						
First week			4.79	5.8	4.0	5.3
Sixteenth week			3.68	4.4		
Lactating sow (400 pounds):						
Second week			8.30	9.6	11.6	15.5
Eighth week			6.51	7.5		

Class of hogs	Fraps		Morrison			Beltsville
	Production values	Feed mixture	Net energy	Feed mixture	Total digestible nutrients	R. O. P.[1] feed consumed
Growing and fattening pigs:	*Therms*	*Pounds*	*Therms*	*Pounds*	*Pounds*	*Pounds*
50 pounds	1.80	2.6	2.00	2.7	2.20	2.7
100 pounds	3.15	4.1	3.45	4.7	3.75	4.7
150 pounds	4.25	5.7	4.60	6.1	4.95	6.3
200 pounds	5.30	7.1	5.35	7.2	5.80	7.3
250 pounds	6.00	7.9	5.90	8.0	6.45	
300 pounds	6.70	8.0	6.45	8.6	7.00	
Pregnant gilt (300 pounds):						
First week			4.4	6.0	4.8	
Sixteenth week			3.6	4.9	4.0	
Pregnant sow (400 pounds):						
First week			4.6	6.2	5.0	
Sixteenth week			3.6	5.1	4.0	
Lactating sow (400 pounds):						
Second week			9.3	12.8	10.0	
Eighth week			7.9	10.4	8.5	

[1] In record-of-performance tests.

The figures for American practice and European practice are based on the data of Mitchell and Kelley (*802*), who intended them as typifying feeding methods rather than as actual standards in common use. The feed mixture used in calculating the allowance in the American practice was a combination of corn and a trinity mixture of tankage, alfalfa-leaf meal, and linseed meal with a mineral supplement proportioned for the appropriate nutritive ratio and based on a 10-percent moisture content. The feed mixtures in the other standards were likewise adjusted in accordance with the type of production involved. Mitchell and Hamilton used a mixture of corn, tankage, middlings, and alfalfa-leaf meal. A combination of corn, barley, wheat middlings, and fish meal was used for the European practice. Morrison's standards (*819*) are well known and need no further explanation. The total digestible nutrients can be calculated for the standards other than Morrison's by the use of the total digestible nutrient values for the feeds in question.

It will be noted that the values given under "American practice" for growing and fattening pigs are the most liberal. Such a standard will probably promote a faster rate of fattening than the others. On the other hand, the allowance for the European practice is lower than the American, as might be expected from the greater emphasis on the production of bacon in Europe, but it does not differ greatly from the other standards.

The estimates in the standard for American practice (*802*) for pregnant gilts and sows were based on the assumption that the gilts would be permitted to gain approximately 100 pounds and the sows 65 pounds during the gestation period.

Brody's data indicated a higher maintenance requirement for boars. Adequate data for the total requirements of boars are apparently lacking.

The last column in table 3 lists some typical figures for average daily feed consumption by growing and fattening pigs in record-of-performance tests at the Agricultural Research Center. These pigs have been self-fed on corn and a mixture of 50 parts tankage, 25 parts alfalfa-leaf meal, and 25 parts linseed meal. Until 1937, a mineral mixture was self-fed in a third compartment of the feeders, but since then this has been mixed with the protein mixture in the proportion of 1 part minerals to 20 parts protein concentrate.

It is noteworthy that the consumption figures for the self-fed ration agree closely with those in the Morrison standard.

The general use of self-feeders for the feeding of growing and fattening pigs in this country has largely submerged the interest in the choice of a suitable standard for popular use. Much of the interest has been directed to the problem of finding the mixtures that will promote the most rapid gains in live weight and the most economical conversion of feed into live-weight gain. As information on protein, mineral, and vitamin requirements has become available and has been applied in the rationing of swine, much greater uniformity has been achieved by hog producers in the rapidity of gains and economy of feed utilization. There is thus good reason to believe that energy standards will continue to serve a very useful purpose in evaluating the success of improvements in rationing with respect to other nutritive essentials.

PROTEIN

The problem of protein requirements is closely associated with that of energy and in actual practice is generally of more concern. Probably the first major advance of recent times in swine nutrition was the finding that an exclusive corn diet supplied too little protein both in quality and quantity for the growing pig. This deficiency and the mineral deficiencies were met by the addition of such feeds as milk or milk byproducts, tankage, fish meal, linseed meal, soybean meal, and similar products.

Much of the supply of these supplements must be purchased by the farmer to supplement the home-grown cereals. Usually the cost of the protein supplements is higher than that of the cereals. It is not profitable to feed excessive amounts of protein beyond the requirements since protein ranks slightly lower than starch as a source of energy.

In computing the protein requirements, it is necessary first to figure the amount of protein that will supply the nitrogen used by the body tissues for upkeep or maintenance. Additional protein above the maintenance requirement is used for growth, reproduction, and lactation. It is possible, by means of balance experiments in which the intake and outgo of nitrogen are determined and also through analyses of the entire bodies of the pigs, to secure rather accurate figures on the amounts of protein actually broken down or built into the body. The determination of the total quantity of feed protein required is complicated by a number of factors. Among these is the fact that the digested protein is a highly variable quantity. The approximate content of total digestible protein has been determined for many swine feeds. For most of the common feeds, 60 to 90 percent of the total protein is digestible. But even after the total digestible protein in a given ration has been estimated, there is another variable to be figured—the portion of the digestible protein that is biologically usable in building tissue. The proteins in many of the common rations have a biological value not greatly in excess of 50 percent.

As an example of the way the protein requirement works out, the following may be cited: Mitchell and Hamilton (*799*) as a result of their swine-type studies concluded that growing pigs of 100 pounds weight required 0.029 pound of protein for maintenance and 0.103 pound for growth, or a total of 0.132 pound daily. On the basis of a biological value of 50 percent for proteins of their ration of corn, middlings, and tankage, the digestible protein required was estimated as 0.264 pound. The digestible protein in the ration constituted approximately 67 percent of the total protein, hence the requirement of total protein was 0.396 pound (50 percent more than 0.264 pound).

Various sets of values have been proposed for the protein requirements of pigs. In most of these the quantity has simply been related to body weight. The relation of the protein required for maintenance to the protein required for basal metabolism has been studied by Smuts (*1086*). On the basis that the protein requirement is proportional to a power of the body weight, he has proposed the use of an adaptation of Brody's equation—$P=0.88M^{0.734}$, in which P is the daily protein requirement in grams and M the body weight in kilograms. This equation is intended to yield generalized values applicable to all species. The values calculated for various weights of pigs are shown in table 4 in comparison with other estimates of protein requirements. The Armsby figures were based on early German and American experiments. Lund (*698*), a Swedish worker, has furnished data for both maintenance and production. It is significant that the figures of Lund and of Smuts agree closely even though obtained by different methods. Among the German investigations the standards of Kellner (*31*) and of Lehmann (*1245*) have been widely quoted, while that of Peterson (*914*) is of comparatively recent origin in Sweden. Fraps of the Texas Agricultural Experiment Station has made extensive studies (*383*) on the digestibility of typical American swine feeds and rations. The source of the data of Mitchell and Hamilton has already been indicated. Their figures for actual protein are 50 percent of those for digestible protein, as are those of Smuts. Brody (*157*) estimated the digestible protein required as four times the endogenous protein (the minimum protein used for maintenance).

Table 4.—*Comparison of standards for daily protein requirements of swine for maintenance*

Weight of pig (pounds)	Armsby	Lund	Mitchell and Hamilton		Smuts		Brody	
	Digestible protein	Digestible protein	Actual protein	Digestible protein	Actual protein	Digestible protein	Endogenous protein	Digestible protein
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
50	0.024	0.044	0.017	0.034	0.019	0.038	0.020	0.079
100	.048	.066	.030	.059	.032	.064	.032	.130
150	.072	.086	.035	.071	.043	.086	.043	.175
200	.096	.106	.038	.075	.053	.106	.054	.216
250	---	---	---	---	.063	.126	.063	.254
300	---	---	---	---	.071	.142	.073	.291

The combined requirements for maintenance and growth are shown in table 5 as digestible protein. As in previous cases, the suggested requirements of a number of workers, both European and American, are given for purposes of comparison. The values are intended for use in conjunction with the energy-requirement figures of the same author or authors given in table 3. For full details on the use of these feeding standards, the reader should consult the references given for each. The figures in the last column are estimates based on the data used for the feed mixture consumption figures in table 3 for record-of-performance pigs at the Agricultural Research Center. The intake of crude protein in the free-choice consumption of the corn and the protein mixture was first obtained, and then digestible protein was estimated as 80 percent of the total crude protein.

When protein-rich feeds are relatively high in price, it is desirable to restrict the protein allowance to the level that most economically meets the needs for maintenance and growth. Up to a certain point, the protein content of the ration has an important bearing upon the leanness of pork. Beyond the point where growth requirements are satisfied, additional protein has little effect. Much of the variation between the proposed requirements shown in table 5 lies in the margin of safety provided, although variations in production requirements exist owing to special factors peculiar to the type of hog being produced.

TABLE 5.—*Digestible protein requirements per day of growing and fattening swine*

Weight of pig (pounds)	European standards				American standards				
	Kellner (true protein)	Lehmann	Lund	Peterson	Armsby	Mitchell and Hamilto	Fraps	Morrison	Beltsville
	Pound	*Pound*	*Pound*	*Pound*	*Pound*	*Pound*	*Pound*	*Pound*	*Pound*
50	0.31	0.35	0.37	0.149	0.30	0.216	0.335	0.39	0.40
100	.45	.63	.52	.238	.38	.264	.495	.55	.60
150	.52	.76	.56	.283	.45	.308	.618	.70	.72
200	.60	.80	.53	.288	51	.304	.712	.78	.74
250	.60				.55	.282	.790	.85	
300							.745	.90	

The lack of influence of the level of protein intake on the nature of the nitrogenous substance added to the body was studied a number of years ago at the Illinois Agricultural Experiment Station (*331*). The bodies of pigs from each of three groups that had received 0.32, 0.70, and 0.94 pound, respectively, of digestible protein per 100 pounds live weight showed no significant difference in the relative content of total nitrogen, soluble nitrogen, protein nitrogen, and nonprotein nitrogen. The influence of high protein intake on the protein metabolism of the bacon pig was studied recently by Woodman, Evans, and Turpitt (*1259*). Their data on pigs averaging 189 pounds in weight showed approximately equal protein retention on a normal daily intake of approximately 65 grams (0.14 pound) of digestible protein and on a high daily intake of 85 grams (0.19 pound).

Often protein requirements are expressed as a percentage of the total ration. On such a basis the protein requirement may be too low or too high, depending on the needs of the animal or the feed consumed. Carroll and Mitchell of the Illinois station (*612*) have reported data which showed that for pigs of 100 pounds live weight or less the ration should contain approximately 18 percent of protein, while for pigs over 100 pounds the percentage of protein may be dropped to 15 percent. The daily total feed intake has an important bearing on the proper protein content of the diet. This fact, as well as the importance of an adequate supply of protein, was shown in a study by Ellis and Hankins (*317*). Three diets varying in protein content from 12.4 to 18.9 percent were fed at a level of 3 pounds of feed per day per 100 pounds live weight. The rates of gain of the pigs increased with increasing protein content of the diet. At 100 pounds live weight, the estimated daily consumption of digestible protein on the one highest in protein content was 0.46 pound and the rate of gain in weight approximately 0.72 pound a day. These data suggest that some of the figures given in table 5 may be too low for adequate protein metabolism, while at the same time they support the medium high values for general application.

Controlled feeding work, such as the foregoing, on the effect of limitation of feed directed particularly at restriction of the energy intake is an effective means of studying the requirements for various elements. Studies on hogs in the Department of Agriculture (*320*) have shown that moderate restriction of feed intake although reducing the rate of gain may at the same time reduce the feed requirement per unit of gain. Work in Great Britain has also given results favorable to restriction as related to efficiency of feed utilization. The Department's work clearly demonstrated that the lean tissue of the carcass, which represents the protein content, can be maintained or even increased by restriction of the energy intake.

This suggests certain problems for further investigation. By working with diets fed at restricted levels it is entirely possible that improvements in the balance of dietary essentials can be effected which will still further increase the economy of gain. It should then be possible to determine the most practical feeding standard commensurate with optimum functional performance, whether it be growth or lactation, and the most economical use of the diet as a whole.

MINERALS

The body of a 225-pound pig contains approximately 5 pounds of ash, or mineral material. Of this amount nearly 4 pounds is in the skeleton, about 0.8 pound in the meat, about 0.2 pound in the organs including the alimentary tract, and slightly less than 0.1 pound each in the skin and the blood. Calcium and phosphorus are the two predominating inorganic elements in the skeleton as well as in the entire body. Following are some estimates of the total quantities of the more common mineral elements in a 225-pound pig:

	Pounds		*Pounds*
Calcium	1. 46	Sodium	0. 16
Phosphorus	. 88	Chlorine	. 13
Potassium	. 34	Magnesium	. 06
Sulfur	. 20	Iron	. 03

Smaller quantities of copper, manganese, iodine, cobalt, and zinc are to be found. All the elements named are known to be required in the nutrition of certain animal species, but the need for adding manganese, cobalt, and zinc to swine rations is uncertain. The requirements are undoubtedly very low and the usual diversified ration probably contains adequate amounts. It has been stated that 1 part per million of cobalt in the diet is adequate for animals that have been studied.

The requirements for calcium and phosphorus for bone formation have been fairly well determined. A lack of calcium or phosphorus retards normal skeletal development and gain in live weight (fig. 3). The bones become fragile and easily broken. In the prevention of these conditions it is important that vitamin D be supplied and that the proportion of calcium and phosphorus be kept within certain limits. The optimum range appears to be within the limits of one and two times as much calcium as phosphorus. Some approximate values for calcium and phosphorus requirements (*803*), expressed as percentage of the dry ration and as net requirements for body needs, are given in table 6.

Ordinarily the requirements as given can be met by the proper selection of feeds. The cereals and cereal products are generally adequate in phosphorus. Protein supplements such as tankage and fish meals contain calcium as well as phosphorus. A concentrate

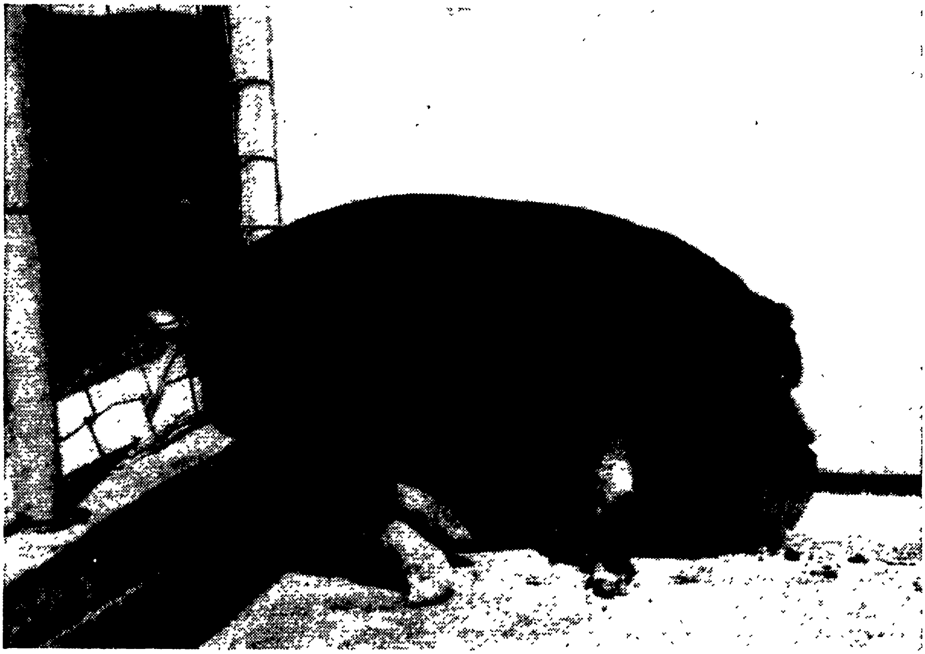

Figure 3.—**A ration too low in calcium causes such rachitic conditions as afflict this pig.**

ration of 9 parts of corn and 1 part of tankage by weight will ordinarily meet the calcium and phosphorus needs of a 50-pound pig grazing on legume pasture.

TABLE 6.—*Daily calcium and phosphorus requirements of hogs*

Condition and weight of pig (pounds)	Calcium		Phosphorus	
	Dry ration	Amount	Dry ration	Amount
Growing pig:	*Percent*	*Grams*	*Percent*	*Grams*
50	0.4	2.5	0.3	1.8
150	.3	3.0	.25	2.5
250	.2	3.5	.2	3.1
Pregnant gilt:				
250, early	.25	4.0	.2	3.5
250, late	.4	7.0	.3	5.0
Lactating sow: 400	.45	10.0	.35	8.0

A lack of salt is marked by poor appetite, unthrifty condition, and failure to grow. Tankage and milk products supply a fair amount of salt, and on the usual ration, swine will ordinarily not consume more than a fraction of an ounce a day when allowed free access to it at all times.

A lack of iodine such as occurs in goitrous areas of the Northwestern States leads to goiter and hairlessness in pigs. It is especially necessary that iodine be present in proper amounts in the ration of the pregnant sow to permit the birth of healthy pigs. It has been stated that a 150-pound hog requires about 0.1 milligram and a sow 0.2 milligram of iodine a day. A common method of supplying iodine when it is shown to be inadequate in the ordinary ration is by adding potassium iodide to the mineral mixture. It is essential to use the utmost care to avoid harmful overdosages.

In addition to iron, copper has been found necessary for the building of the hemoglobin in red cells. There is some evidence that manganese and possibly cobalt are involved. Milk is lacking in an adequate supply of iron and copper for the needs of the nursing young. If suckling pigs are prevented from obtaining an outside supply from the dirt of the hog barn, from dry feed, or from some other source, they may suffer from anemia. Affected pigs show paleness of the mucous membranes, sluggishness, lack of vigor, and failure to grow normally. There are various procedures for preventing the occurrence of anemia among suckling pigs. Medication with iron and copper salts is sometimes necessary, though the amounts required are small. An effective method in winter, when the animals are confined, consists in dissolving 10 grams of ferrous sulfate and 1.5 grams of copper sulfate in water and sprinkling the solution on 50 pounds of soil, which is placed inside the pen. The needs of the pregnant sow should not be overlooked. During the late weeks of pregnancy, several times her normal daily body needs are built into the embryos.

A few suggested mineral mixtures containing various elements that may be lacking in the swine ration are given in table 7. These mixtures may be made available in a self-feeder or mixed in the feed at the rate of 1 to 2 pounds per 100 pounds of the feed mixture. The minerals usually can be mixed at home much more cheaply than they can be purchased in a commercial mixture.

TABLE 7.—*Suggested mineral mixtures for hogs*

Mixture No.	Ground limestone	Steamed bonemeal	Salt	Iron oxide	Copper sulfate	Potassium iodide	Charcoal	Wood ashes
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
1	33	23	33					
2	50	27.97	20	2	0.01	0.02		
3	40	40	20			.03		
4	25	50	5				10	10
5	75		25					
6		75	25					

VITAMINS

Thus far the experimental work on vitamin requirements of swine has shown a definite need for vitamins A and D. The requirement for vitamin C, if any, is very small. Recent work has shown that several of the factors in the vitamin B complex are needed. These include riboflavin, nicotinic acid, the fractions obtained by extraction and separation by chemicals (called the eluate and filtrate fractions), and probably vitamin B_1. The identity of substances essential for the pig in the eluate and the filtrate fractions of liver, rice bran, yeast, and other sources is still obscure. Vitamin B_6, lack of which causes rat dermatitis, has been identified in the eluate fraction. The development of dermatitis in chicks has been found to be due to lack of a factor or factors in the filtrate fraction.

Night blindness appears as the first easily recognized evidence of a lack of vitamin A in the hog ration. It has been found that pigs may lack normal vision in semidarkness and yet gain normally. If the dietary deficiency persists, growth will be retarded sooner or later, and other physical manifestations will be evidenced such as diarrhea, muscular incoordination, and paralysis of the hind legs (*545*). Addition of vitamin A, or of carotene, the precursor of vitamin A, either in concentrated form or more properly in natural sources available on the farm as green feed, yellow corn, or bright-green alfalfa hay or leaf meal to the ration will cure or prevent the symptoms of vitamin A deficiency.

Work at the California Agricultural Experiment Station (*447*) has shown that the minimum requirements for vitamin A to prevent night blindness and promote normal growth and general thrift are approximately proportional to body weight for various species of animals. It is stated that 1.0 to 1.30 milligrams of carotene from plant material or 0.3 milligram of vitamin A from cod-liver oil per 100 pounds body weight meets these requirements.

Reproduction may be impaired or prevented by an inadequate supply of vitamin A. At the Texas Agricultural Experiment Station (*459*) sows on a vitamin A-deficient ration have farrowed litters with a variety of defects including blindness, failure to develop eye tissue, cleft palate, and harelip. Gilts reared at the California Agricultural Experiment Station on diets low in vitamin A have failed to conceive (*554*). The difficulty was corrected by addition of cod-liver oil to the ration. The exact requirements for reproduction and lactation are not known. Possibly additional amounts over the minimum suggested on a body-weight basis are needed. It should be possible to determine fairly accurately the amount needed for lactation in the sow to insure an adequate intake for the nursing pig.

Vitamin D, the sunshine vitamin, is associated with the utilization of calcium and phosphorus in forming bone. When the calcium and phosphorus supply in the diet is abnormal either in content or in proportion of one element to the other, lack of sufficient sunshine or dietary vitamin D is especially serious and leads to the development of stiffness, enlarged joints, lameness, poor growth, and other evidences of rickets or other maldevelopment of bones. Providing calcium and phosphorus in the amounts and proportions already indicated usually suffices for the prevention of rickets when the pigs are exposed to sunshine in the fields or outside pens. Winter confinement in the northern latitudes or in cloudy areas with little or no exposure to sunshine sometimes leads to the development of rickets. Under these conditions it is advisable to add vitamin D to the diet. The cereals used in hog feeding are generally low in vitamin D. Of the protein supplements, blood meal, tankage, and fish meal are of questionable value, although the latter is sometimes effective in the prevention of rickets. Alfalfa, especially when cured in the sun, has proved a very useful supplement for winter feeding.

Nicotinic acid, which appears to be the substance that cures human pellagra, was found necessary for the growth and well-being of swine by Chick, Macrae, Martin, and Martin (*202*) of England in 1938. Pigs fed a diet of corn, purified casein, and salt mixture developed diarrhea, dermatitis, and loss of appetite. The skin became a dirty yellow color, covered with scabs and largely denuded of hair. The addition of nicotinic acid to this diet entirely cured or prevented the development of these disturbances.

Hughes of the California Agricultural Experiment Station (*556*) has reported experiments that confirmed the English work on the need for nicotinic acid and also showed that a lack of riboflavin was associated with poor growth and poor feed utilization. The California work also suggested that thiamin (vitamin B_1) and substances in both the filtrate fraction and the eluate fraction were necessary for the nutrition of the pig. It appeared to be necessary to add several of the factors in the vitamin B complex to the basal diet to secure healthy, fast-growing pigs.

In cooperative studies with the Bureau of Animal Industry on the growth requirements of pigs, Wintrobe (*1241*) of Johns Hopkins University, found that growth was accelerated when either thiamin or riboflavin was added to a basal diet essentially free of the water-soluble vitamin factors.

The English workers have continued their investigations on the requirements of the pig for the components of the vitamin B complex (*203*). Besides recognition of the need for riboflavin and nicotinic acid, they have found that both the eluate and filtrate fractions were necessary for health and growth. A lack of the filtrate fraction from liver extract leads to a cessation of growth, development of a flaccid palsy of the hindquarters, and eventually death. Deprivation of the eluate fraction from liver caused a certain type of anemia, with low corpuscular volume and low hemoglobin, and also epileptic fits.

More work needs to be done on the relation of vitamin E to fertility in swine.

Much work remains to be done to establish the quantitative requirements of swine for the vitamin factors, the content of these factors in hog feeds, and the conditions under which swine diets require special supplementation. Yellow corn is known to be a good source of vitamin B_1 and riboflavin as well as of vitamin A. It is low in nicotinic acid but apparently furnishes an adequate supply of the factors in the eluate and filtrate fractions when fed as the main part of the diet. Wheat, barley, and especially brewers' rice are low in riboflavin. Although processing methods probably result in some destruction of the vitamins, animal and marine byproducts, including skim milk, buttermilk, whey, tankage, and meat and fish meals, undoubtedly have high value as supplements for supplying vitamins as well as protein and minerals. Finally the leafy forages have demonstrated their general usefulness as protective feeds.

WATER

The importance of water in the economical production of hogs should not be overlooked. A certain amount is supplied daily in wet slops when this system of feeding is used. With self-feeding, hogs need access to good fresh water at all times. Otherwise they will not consume sufficient dry feed to make the most rapid growth. Water may also be a carrier of certain mineral elements such as iron, calcium, magnesium, and sulfur. Evvard (*351*) of the Iowa Agricultural Experiment Station found spring pigs consumed more water than fall pigs up to approximately 200 pounds in weight. The amount of water consumed daily at will by spring pigs averaged 3.3 pounds for the 25-pound pig and increased to 11.5 pounds for the 175-pound hog. As the pig gets older it requires proportionately less water, because it consumes less feed per unit of weight and the water content of the body is decreasing.

PRACTICES IN SWINE FEEDING

by J. H. Zeller and N. R. Ellis[1]

HERE the authors describe the various kinds of feeds and systems of feeding used in the United States, and tell how to use the different carbohydrate and protein supplements to get economical results; what to do to avoid soft pork; how to make sure of furnishing adequate amounts of minerals and vitamins; and how to meet the special needs of growth, pregnancy, and lactation.

ALTHOUGH the hog industry is based on corn, the hog can utilize a larger variety of feeds to greater advantage, perhaps, than any other farm animal. Small-grain crops—wheat, barley, oats, rye, and the kafirs—can be utilized as a major component of the swine ration, and root crops, such as peanuts, potatoes, and sweetpotatoes, are also of value. Byproducts of the fishing industry, the packing industry, and the industries milling wheat, rice, cottonseed, and soybeans are used in hog feeding; and byproducts of the dairy industry, such as skim milk, buttermilk, and whey, together with various kinds of home-grown forage and pasture crops, all play an important role in supplementing the cereal-grain ration.

The modern hog feeder uses the relation of prices between corn or other feeds and the selling price of hogs as an indication of when to increase or decrease his production program. The cost of feed alone, including pasture, is estimated to make up approximately 75 to 85 percent of the total cost of producing marketable hogs. The cost of feed varies greatly from year to year, or even within shorter periods; It varies also in different sections, owing to local conditions of supply and demand. With the price of feed playing such an important role in the production cost of hogs, the producer must always be alert to use locally available feeds, properly balanced, to give the most economical returns.

Whenever hog prices have been relatively high compared to the price of corn, farmers have usually increased their production of hogs. A year to a year and a half from the time such a decision was made the increased supply of hogs reached the market, which soon became oversupplied, causing hog prices to drop. Hog producers then began to reduce their breeding operations. This tendency of the producers to readjust production to price always seemed to carry them too far in the opposite direction. This is the reason for the more or less regular cycles that have characterized hog prices.

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The relation, then, between feed prices and selling prices of hogs tended to be self-perpetuating. Each period of favorable hog prices caused too great an expansion in production before prices became unprofitable, and each period of unfavorable prices caused too great a reduction before favorable prices were restored. Those farmers who had not varied their production from year to year or who had timed their expansion opposite to the majority were the ones who usually made the greatest profit.

Any leveling out of these cycles in hog production naturally will react favorably on the industry as a whole.

Changes in the type of hogs have been made to meet economic demands of consumers. Since the swine industry of the United States has been founded mainly on the corn crop as the basal feed, the lard type of hog has been predominant. The bacon-type breeds, as such, have been found in small numbers in scattered sections of the country but have not attained the popularity of the lard-type breeds. When consumer demand dictated the need for a hog with less fat and leaner hams and bacons, breeders have utilized the lard-type breeds in an endeavor to develop a type to meet the requirements.

SWINE PRODUCTION IN THE UNITED STATES

The United States is self-contained from the standpoint of swine production. Hogs can be raised in practically all sections of the country on a great variety of feeds that are usually produced locally. In this respect the system here differs from those found in some foreign countries. England, for example, imports large quantities of cereal grains and protein supplements for use in the feeding of hogs. Ireland depends to a certain extent on imports of cereal grains and other feeds to supplement the local potato and milk byproducts upon which its swine industry is largely based. The swine industry of Denmark has been built up as a byproduct of the dairy industry, with milk and whey supplementing home-grown and imported cereals. In recent years, Germany has been driving toward economic self-sufficiency in the swine industry, with a reduction of imports of cereals and a wider use of home-grown crops such as potatoes, sugar beets, and green forage. This results in a less concentrated ration.

Since hogs are produced and fattened in all the 48 States, there are naturally great differences in the feeds used and in methods of feeding and management. While the principles involved in feeding practices apply equally well to all parts of the country, the problem of production may be viewed from a sectional standpoint. The country may be divided into four major regions: (1) The Corn Belt, which includes the North Central States; (2) the South, which includes the South Central States; (3) the Atlantic coast region, which includes the North Atlantic and South Atlantic States from Maine to Florida; (4) the Western States. Figure 1 graphically defines the four regions and shows the number of hogs on farms January 1, 1939, as estimated by the Bureau of Agricultural Economics.

THE CORN BELT

The Corn Belt includes the 12 States comprising the North Central division. During 1936 this group of States produced 60 percent of the total corn crop of the country and had on farms January 1, 1937, 62 percent of the total hog population; and during 1937 they produced 72 percent of the total corn crop and had on farms January 1, 1938, 63 percent of the total hog population. Although an increase of over 3 million head from January 1, 1938, to January 1, 1939, is indicated, the percentage of the total hog population in the Corn Belt remained the same—63 percent. The relation of production of corn to production of hogs in the six States raising the largest numbers of hogs is shown in table 1. The relationship between the production of corn and the number of hogs on farms the following January, to be fed out, is fairly close. Even adverse conditions such as occurred during the drought of 1934 and again when weather conditions shortened the corn crop in parts of the area in 1936 did not disturb the relationship as much as might have been expected. The fact that the percentage of the total hog population produced in these States held rather constant during the 5-year period indicates that production did not wholly depend upon the corn crop.

Hog production is one of the main livestock enterprises throughout the Corn Belt. As a general rule it is profitable over a period of years. It fits into the operating plan used on most farms and aids in the marketing of a large part of the corn crop. On some farms hog production is the main livestock enterprise, while on others it is a side line to other livestock programs, such as raising beef cattle and dairying.

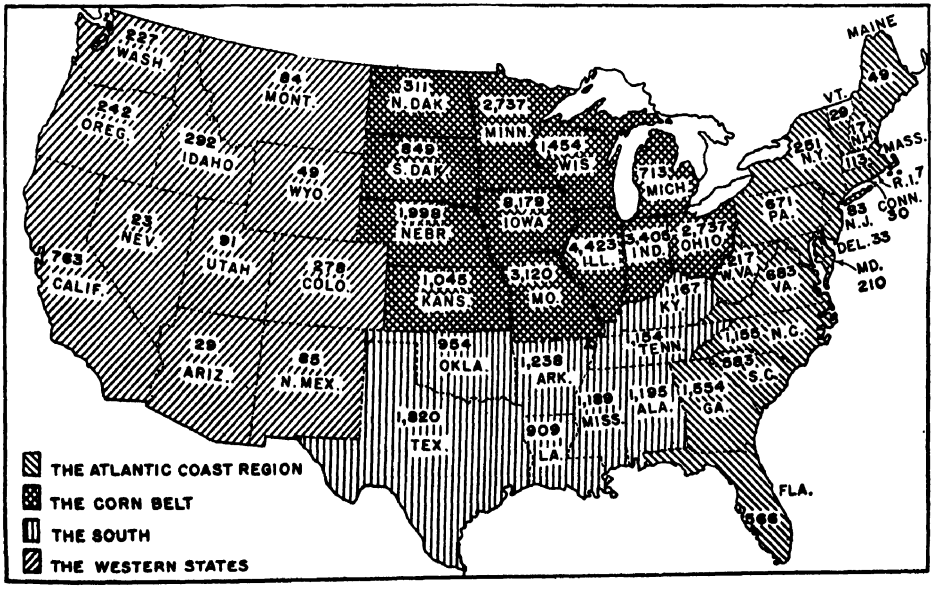

Figure 1.—Numbers (thousands) of hogs on farms in the United States, by States, and the four major hog-producing regions, January 1, 1939.

TABLE 1.—*Relation of corn to production of hogs in 6 leading hog States, 1934–39*

State	Production of corn				
	1934	1935	1936	1937	1938 [1]
	1,000 bushels	*1,000 bushels*	*1,000 bushels*	*1,000 bushels*	*1,000 bushels*
Iowa	195,895	373,388	190,434	498,690	468,923
Illinois	146,760	318,510	217,751	449,616	379,350
Indiana	96,298	162,260	116,510	213,840	173,389
Missouri	26,482	72,890	40,032	117,242	117,720
Nebraska	21,363	106,630	26,859	82,992	107,735
Ohio	92,200	160,556	121,605	163,228	156,992
Total	578,998	1,191,240	713,191	1,525,608	1,404,109
Total, United States	1,377,126	2,303,747	1,507,089	2,651,284	2,542,238
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Proportion of entire crop produced by 6 States	42.04	51.84	47.32	57.54	55.23

State	Hogs on farms Jan. 1				
	1935	1936	1937	1938	1939 [1]
	1,000 head	*1,000 head*	*1,000 head*	*1,000 head*	*1,000 head*
Iowa	6,250	7,250	6,525	7,504	8,179
Illinois	3,510	3,860	4,053	4,134	4,423
Indiana	2,675	2,942	3,236	3,182	3,405
Missouri	2,400	2,760	2,622	2,622	3,120
Nebraska	2,034	2,238	1,567	1,598	1,998
Ohio	2,160	2,333	2,706	2,607	2,737
Total	19,029	21,383	20,709	21,647	23,862
Total, United States	39,004	42,837	42,948	44,218	49,011
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Proportion of entire crop produced by 6 States	48.79	49.92	48.22	49.30	48.69

[1] Preliminary figures.

While corn ranks first as the main cereal crop used in feeding hogs in the Corn Belt, other cereal grains such as wheat, oats, barley, and rye are used quite extensively, sometimes as a partial substitute for corn. In the northern section of the Corn Belt the small grains assume considerable importance in swine feeding.

Protein-rich feeds to balance the protein deficiency of the common farm grains are readily available to hog feeders in this region. Byproducts from the dairy industry, such as skim milk, buttermilk, and whey, furnish protein feeds of animal origin. Tankage, a byproduct of the packing industry, is manufactured in large quantities within the region and makes available an animal protein without excessively high transportation charges for long shipments.

The rise of the soybean to prominence in the farm program in the last 15 years in this region has made available a home-grown plant-protein supplement. Soybeans are grown on many farms and are used in various ways. Much of the harvested crop is milled, and the meal remaining after removal of the oil is used in hog feeding. Other proteins of vegetable or plant origin, such as cottonseed meal, linseed meal, and gluten meal, are often fed in combination with proteins of animal origin.

Pastures are used quite extensively as a further source of proteins, minerals, and vitamins. Permanent pastures of bluegrass, alfalfa, and the clovers make grazing available during the growing season. Temporary pastures are used to furnish grazing at stated intervals or to supplement the permanent pastures.

The hog has also been used quite extensively in the Corn Belt in helping to harvest crops at different seasons of the year. Corn is fed not only on the cob, shelled, or as meal in the feed lot, but is hogged down by turning the hogs into the field and allowing them to harvest the crop. Soybeans are commonly planted with corn for hogging down. The supplemental feeding of a small amount of tankage daily with access to a mineral mixture completes a well-balanced ration.

Pigs weighing 75 to 100 pounds are used to follow steers in the feed lot and glean the waste that otherwise might be lost. The gains made by pigs following cattle increase the returns from the cattle-feeding enterprise. The method of feeding and amount of feed given to the cattle influence the requirements for additional grain and protein supplement for the hogs. Where cattle are fed largely on grain the practice of feeding a small amount of protein supplement to the hogs daily helps to balance the ration.

THE SOUTH

Approximately 20 percent of the total hog population on January 1, 1939, was found in the eight Southern States of Kentucky, Tennessee, Alabama, Mississippi, Arkansas, Louisiana, Oklahoma, and Texas. In number of hogs this section ranks next in importance to the Corn Belt. Formerly hog production was retarded somewhat by the preeminence of the cotton crop. Because of the ravages of the boll weevil, together with campaigns for soil improvement, the hog is gradually finding a more important place in the new diversified agriculture in the South. In parts of the South small numbers of hogs that are allowed to shift for themselves on free range in the woods may still be found. This practice is decreasing, however. Farmers are realizing the importance of better feeding practices. The larger use of soil-improvement crops together with favorable climatic conditions makes possible year-round systems of grazing for hogs in many parts of the South. The past decade has seen many changes in systems of feeding and management, and as a result the South is now producing a much more desirable market type of hog.

The feeds vary somewhat according to localities. Although corn can be grown in the South, it does not assume the importance in swine feeding that it does in the Corn Belt. The yield per acre is much smaller because of climatic and soil conditions.

Grain sorghums, which produce a fair crop on soil too thin for corn, are similar to corn in composition and are substituted where they are available. Kafir, milo, sorgo, and feterita are of importance in swine feeding in Oklahoma and Texas.

One of the southern crops associated closely with pork production is the peanut. Hogs are used to glean the peanut fields after the crop is harvested or are turned into the field to harvest the entire crop.

Byproducts from the rice industry such as rice bran, rice polish, and brewers' rice are utilized in hog feeding, especially in Arkansas, Louisiana, and Texas. Both rice bran and rice polish, because of their high fat content, produce soft pork unless fed in small amounts in combination with other nonsoftening concentrates, such as corn or brewers' rice.

Of the root crops used in this area for swine feeding, sweetpotatoes are of most importance. They can be grown on soil that is sandy and too thin for good corn production. Hogs are used to clean up the fields after sweetpotatoes have been dug.

Various locally produced protein concentrates are available, including tankage, shrimp meal, and milk byproducts, all of animal origin, and cottonseed meal, peanut meal, and ground alfalfa, of plant origin.

THE ATLANTIC COAST REGION

The 17 States in the Atlantic coast region had on farms on January 1, 1939, approximately 13 percent of the total hog population. Only 2.5 percent were in the 9 North Atlantic States. Pennsylvania alone accounted for over half the number in that area. The 8 States in the South Atlantic group accounted for 10.5 percent of the total number of hogs. Georgia and North Carolina were the principal hog-growing States in the southern part of the region.

The majority of swine enterprises in the North Atlantic States are small, and most producers feed only a few pigs for home use. In Pennsylvania hogs are maintained in small units on a large number of farms. Most farmers raise a surplus for sale each year, thereby augmenting their cash returns. Most farms have a diversified livestock program with the hog used as a side line to cattle feeding, dairying, or other enterprises. In addition, hogs are used to glean the fields and consume a variety of feeds that otherwise might be wasted. Grain crops such as corn, barley, oats, and rye are marketed through hogs. The general plan of feeding follows closely the practices in the Corn Belt. Protein supplements of tankage, fish meal, middlings, and skim milk are used to supplement the grain ration. Pasture crops of alfalfa, the clovers, soybeans, rape, and winter rye are commonly used.

The principal feeds used in fattening hogs in the South Atlantic region are somewhat similar to those used in parts of the South, especially in Arkansas, Mississippi, and Alabama. Corn is used in the dry lot, or for hogging down alone or in combination with peanuts or soybeans. The protein supplements available are fish meal, cottonseed and soybean meals, tankage, and milk byproducts.

Peanuts are used extensively as a hog feed in parts of Georgia and Florida and are usually grazed alone or in combination with corn. Sweetpotatoes and chufas are both grazed in the same States.

Year-round systems of crop rotation are being worked out for different sections so that hogs can be grown and fattened on mature crops. Usually such crops as corn, peanuts, sweetpotatoes, soybeans, and oats are planted at different times to furnish a succession of mature grazing crops.

Pasture crops are important since they can be utilized during a relatively large part of the year and furnish a variety of home-grown protein and mineral supplements at a reasonable price. Crops used to advantage are alfalfa, the clovers, rape, soybeans, cowpeas, Sudan grass, winter oats, rye, and sorgo. Sudan grass and sorgo pastures are of value because their dense stands permit much heavier grazing than such crops as soybeans and cowpeas. Limited feeding of corn to pigs on green forage to weights of 75 to 100 pounds is practiced in some sections. At these weights pigs are turned into the fields to hog down corn.

A large number of hogs in the Atlantic coast region are grown and fattened on garbage near the larger cities. Most garbage is more or less a balanced ration and no supplemental feed is required. Some feeders, however, supplement the garbage with feeds such as corn, barley, and middlings in order to obtain faster gains. Some garbage feeders follow the plan of raising their own pigs. The sows are usually fed on garbage and the pigs are started on garbage as sucklings. Some feeders, on the other hand, purchase pigs weighing 75 to 100 pounds and finish them on garbage. Hogs relish raw garbage more than cooked garbage. However, recent investigations conducted by the Zoological Division of the Bureau of Animal Industry show that the occurrence of trichinae in hogs fed raw garbage is eight times as great as that in hogs fed cooked garbage. Cooking the garbage helps to destroy such organisms.

THE WESTERN STATES

Less than 5 percent of the total hog population on January 1, 1939, was found in the 11 States of the region west of the Corn Belt and the South. A large part of this region is mountainous, arid, or a plain and range country better adapted to sheep and cattle than to hogs. Eighty-five percent of the hogs raised in the region are found in California, Idaho, Colorado, Oregon, and Washington.

The feeds used, alone or in combination, in making up the basal ration are corn, barley, wheat, rye, oats, and hog millet. The grain sorghums—kafir and milo—and rice bran and rice polish, byproducts of the rice-milling industry, are used to some extent. All these feeds except corn should be ground or rolled for most economical returns in the ration for growing and fattening hogs. Protein supplements of animal origin fed in this area are fish meal, tankage, and skim milk. The plant proteins, such as wheat middlings, alfalfa, linseed meal, cottonseed meal, and soybean meal are of more importance, however.

In California, barley is the principal cereal grain used. The grain sorghums, rice bran, and rice polish are also fed. The climate of California is mild and pasture is available most of the year. Alfalfa grows well and furnishes a legume of excellent quality to supplement grains and animal protein. A large number of hogs are fed garbage in the vicinity of the larger cities under conditions similar to those on the Atlantic coast. Some feeders are grain-feeding the garbage-fed hogs prior to marketing in order to improve the product. Low-grade fruits and vegetables are sometimes utilized in swine feeding. Raisins, figs, and prunes are carbohydrate feeds and usually give best results when combined with barley or the grain sorghums and supplemented with a protein concentrate. Tuber and root crops such as artichokes, sweetpotatoes, beets, and potatoes fed in combination with other feeds furnish nutrients and add variety to the ration.

FEEDS FOR ENERGY AND FATTENING

The chief sources of heat and energy in the diet are the carbohydrates and fats. Materials rich in these substances are popularly called fattening feeds. Carbohydrates are found in abundance in the cereal grains, corn, wheat, barley, rye, oats, and other farm-grown feeds that make up the basal part of the swine ration. Fat is supplied in small amounts in the cereal grains and in protein supplements of both animal and plant origin. Certain hog feeds, including peanuts and soybeans, are high or moderately high in fat. The fuel value of fat in the ration is about 2.25 times as great as the fuel value of an equal weight of carbohydrates or protein. In the fattening animal, the fats in the diet are utilized to form body fat. Swine are unusually efficient, however, in converting sugars and starches into body fat.

Corn is a carbohydrate feed, and because of its deficiencies in protein, minerals, and vitamins, it needs to be supplemented with feeds high in these nutrients. Hogs fed on corn alone usually gain slowly and require a large amount of feed per unit of gain. White corn, especially, is deficient in vitamin A and for young pigs in dry lot or hogs on winter rations deprived of access to pasture it should be supplemented with at least 5 percent of alfalfa-leaf meal or good-quality alfalfa hay in addition to an animal protein supplement of skim milk, tankage, or fish meal. If young pigs are raised to a weight of 100 pounds on normal rations containing a generous supply of vitamin A, they may store enough of the vitamin in their bodies to permit economical gains of approximately 100 pounds before malnutrition troubles develop if they are changed to a white-corn ration. Corn may be fed on the cob or shelled and produces good results when fed in properly balanced rations to all classes of hogs. Usually it does not pay to grind corn for hogs unless it is desirable to combine it in definite proportions with other feeds, in which case it is easier to make a more uniform mixture with ground corn.

The grain sorghums, kafir, milo, sorgo, feterita, and others, grown in regions where climatic and soil conditions are unfavorable for corn, have approximately 90 percent of the feeding value of corn. Experiments have shown that better gains are produced when the grains are ground and fed dry rather than soaked.

Wheat is usually regarded as a cash crop and milled for human consumption. There are times, however, when the relation between the price of wheat and that of corn makes it profitable to feed wheat to livestock. Pound for pound, good-quality wheat on the average is approximately 5 percent more efficient than corn in producing gains on hogs. Wheat is higher in protein and carbohydrates, contains less fat, and is slightly higher in total digestible nutrients than corn of the same dry-matter content. Since the protein in wheat is deficient only in the essential amino acid lysine, while corn is deficient in both lysine and tryptophane, usually less protein supplement is required to balance the ration when wheat is used. Wheat, like white corn, is deficient in vitamin A. Because the wheat grain is small and rather hard it should be ground for most economical utilization. Wheat may be fed as the sole grain or it may be combined with other grains. Wheat byproducts such as standard middlings, flour middlings, and red-dog flour are quite commonly fed to hogs in varying amounts as partial substitutes for corn. Generally speaking, wheat byproducts may replace up to one-third of the corn in the ration with good results. When wheat is low in price or damaged by insects it may be more profitable to market it through hogs than in other ways.

Barley is slightly higher in protein content than corn, but should be supplemented with animal protein feeds and pasture or dried-legume forage in order to furnish essential amino acids, minerals, and vitamins, especially vitamin A (*555*).[2] The relative value of barley compared to corn in the swine ration depends on the weight of the barley per bushel. Experiments have shown that the efficiency of barley as a hog feed compared with corn ranged from 92 percent for heavy barley weighing 49 pounds per bushel to 74 percent for light barley weighing 41 pounds per bushel. Grinding barley before feeding improves its feeding value enough to more than pay the cost of the operation. Pound for pound, barley should be cheaper than corn when it is used as a hog feed, since it is not so efficient and an additional expense is incurred for grinding.

Oats are considered a good feed for growing pigs and for brood sows, but they are too high in fiber and too bulky to be used exclusively as the fattening ration for hogs. In addition it is known that a diet of oats needs to be supplemented in protein, vitamin A, and calcium. For fattening hogs oats are usually fed in combination with other grains such as corn, wheat, or barley. Grinding oats increases their feeding value for growing and fattening pigs. When good-quality ground oats, weighing 32 pounds to the bushel, do not make up more than one-third of the ration they are considered to be equal in feeding value, pound for pound, to corn. When oats make up more than one-third of the ration for fattening hogs their value decreases to 65 to 70 percent of the value of corn. Hulled oats usually are more expensive to prepare than ground oats. To be used profitably as a fattening feed for hogs, oats should be as cheap as or cheaper than corn, pound for pound.

Rye is often fed to hogs and is considered to have a feeding value approximately 90 percent that of corn. Usually best results are obtained when rye does not make up more than one-half the ration for fattening hogs. Equal parts of ground rye and corn or ground rye and ground barley properly supplemented with proteins of good quality give good results. Generally rye is not very palatable and hogs lose their appetite for it if fed too much. Usually the feed consumed daily by pigs on a rye ration decreases as the proportion of rye is increased. When rye is cheap in price compared with other grains it can be substituted economically for part of the grain concentrate in the ration.

The several byproducts of the rice-milling industry available for feeding hogs are classed as carbohydrate feeds. In limited amounts, rice bran is considered to have a feeding value about 90 percent of that of corn. Rice bran is high in fiber and because of its bulkiness should be fed in combination with corn or tankage. Not more than 50 percent of the ration should be made up of rice bran because of its tendency to produce soft pork.

Brewers' rice is made up of the small broken kernels of rice. It is similar to corn in composition. When properly supplemented with an animal protein such as tankage, fish meal, or skim milk, it produces gains comparable to those made on a corn ration. The carcasses of hogs fed on brewers' rice are very firm.

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[2] Italic numbers in parentheses refer to Literature Cited, p. 1075.

Molasses is sometimes used in the swine ration. It is considered to have a feeding value approximately 90 percent that of corn when it is substituted for corn up to about 20 percent of the ration. It is usually unsatisfactory when substituted for all the corn in the ration. When it is cheaper than corn or other grain, molasses may be substituted for a part of the grain in the ration. Molasses may cause scours in pigs unless they are started on it gradually and then fed it in limited quantities.

Sweetpotatoes are fed to a considerable extent in the South. They are high in starch in proportion to their protein and mineral content. Best results are usually obtained when pigs grazing sweetpotatoes are given approximately 2 pounds of grain a day per 100 pounds live weight in addition to a protein supplement of tankage or fish meal, and a mineral mixture. Hogs that have access to a soybean field when grazing sweetpotatoes need less protein supplement. It requires approximately 4 pounds of sweetpotatoes to equal 1 pound of grain when fed to hogs in dry lot, while approximately 5 pounds of sweetpotatoes are required to equal 1 pound of grain when the crop is hogged down.

White or Irish potatoes are not so important a source of carbohydrate in the hog ration in this country as in Europe. They are used as a hog feed when they have little value on the market and grain prices are high. It is necessary to boil or steam potatoes for hogs as they are not palatable in the raw state and in large amounts may cause scours. Pigs fed heavily on potatoes will not show the bloom or apparent finish of those fed on a more restricted allowance. Boiled potatoes may be used to replace not more than 50 percent of the grain ration. From 350 to 450 pounds of boiled potatoes are required to equal in feeding value 100 pounds of standard cereal grains. The importance of balancing a potato ration with adequate protein and minerals must be stressed. A heavy potato ration may be fed to bred sows in the early stages of gestation, but as pregnancy advances it should be gradually reduced and entirely eliminated prior to and immediately after farrowing.

Other root crops are of little importance in swine feeding in this country. These crops are succulent and probably are most valuable for brood sows and fall pigs during the winter months when pasture crops are not available. They usually contain 80 to 90 percent of water and do not have much actual feeding value. Under favorable conditions it requires 5 to 10 pounds of roots to equal the feeding value of 1 pound of grain. Best results are obtained when the roots are cut in small pieces and fed raw.

FEEDS THAT CAUSE SOFT PORK

One of the most important factors in determining the quality of pork products is firmness (*469*, *471*). The products of soft and oily carcasses frequently suffer a severe cut in price. While no reliable average figures are available, it is estimated that soft hogs may be docked 10 to 25 percent of the market price.

There are a number of factors that have an influence on firmness, the chief of which is feed. The quantity and characteristics of the fat in the various feeds greatly influence the firmness of the body fat of the hog. Hogs fed on large amounts of feeds of plant origin that are high in oil usually produce soft carcasses.

Feeds that produce soft pork can usually be grown cheaply. The hog producer should consider how he can use them to best advantage. When they are used for young growing pigs, a sufficiently long subsequent period on feeds that produce a hardening effect on the carcass may improve the quality of the product enough to make it acceptable on the market. Generally speaking, it requires three to four times as much gain on hardening feeds as was produced on the softening ration to make a satisfactory product.

The feeds most commonly used that produce soft pork are peanuts, soybeans, and mast (acorns and nuts on which pigs graze in wooded areas). Mention has been made of rice bran and rice polish. Corngerm meal is another mill byproduct that must be classed as a softening feed.

Like soybeans, peanuts contain a much higher percentage of protein than the cereal grains. Because of their relatively high oil content together with a fair proportion of starches, they are both properly classed as fattening feeds. On a quantitative basis these feeds would not be expected to require additional protein or carbohydrate. Unfortunately, exclusive feeding of either is marked by the production of soft pork and by only moderately good rates of growth, owing to the rather poor quality of the protein as well as deficiencies in minerals and vitamins. While pigs make good gains on peanuts alone, especially when grazed, the addition of small amounts of animal protein such as tankage or fish meal fed in the dry lot has been found to increase the rate and economy of gains. The addition of a mineral mixture and of legume hay or meal as a source of carotene is also advisable, especially in lengthy feeding periods.

Soybeans, because of their widespread adaptability to different soils and climatic conditions, are a popular hog feed. They can be used to best advantage when they form part of the protein supplement rather than the basal part of the ration. Under ordinary conditions when soybeans used in this way do not form more than 10 percent of the ration of pigs starting at 100 pounds weight, carcasses of good quality will be produced. The addition of tankage to a soybean ration improves its quality. The soybean is low in calcium and phosphorus and a mineral mixture of these elements should be fed with a soybean ration for best results.

In some sections of the country, acorns, usually fed by mast grazing, assume considerable importance in feeding hogs and help to cheapen production. The pork produced is usually soft and of poor quality. For best results hogs should be finished on a grain ration following mast feeding.

BREWERY AND DISTILLERY BYPRODUCTS

Wet brewers' grains, a distillery byproduct, may be fed to fattening hogs when such concentrates as grain are supplied in addition, but the feed is too watery to be used alone. Usually about 4 pounds of wet brewers' grains are equivalent in feeding value to 1 pound of the dried. The composition and feeding value of wet brewers' grains vary widely, depending on the kind of grain predominating; rye is of considerably less value than corn. Because of their low nutritive value these feeds are not economical unless the haul is short or unless they can be purchased at less than one-fourth the price of grain.

Distillery slop may be used in the ration for fattening hogs or for brood sows if it is fed in addition to a liberal grain ration and supplemented with such proteins as fish meal or tankage. From 1 to 1½ gallons per 100 pounds live weight daily is considered a good allowance.

PROTEIN FEEDS

Protein feeds are necessary to maintain and build body tissue. Because hogs grow at a more rapid rate than other farm animals in relation to their weight, their feed requirements change rapidly. In a comparatively short time there is a change from the high protein requirement of growth to a lower protein requirement during the fattening period after growth has been attained. Because of the low protein content of farm-grown grains used in swine feeding, the protein supply in the ration needs to be considered carefully.

The deficiency of grains in protein is corrected by adding protein-rich feeds such as milk and milk byproducts, tankage, fish meal, or linseed, cottonseed, soybean, or alfalfa meal to the cereal part of the ration. Home-grown protein feeds are usually not so abundant as carbohydrate feeds and it is often necessary to purchase them. Although they are higher in price than carbohydrate feeds, the cash outlay usually yields greater returns in increased rate of gain and better utilization of feed per unit of gain.

Skim milk is a valuable protein supplement for hogs when fed in connection with corn or other feeds of like nature. It should be fed in limited quantities for the most economical returns. Soon after pigs are weaned, not more than 4 or 5 parts of skim milk to 1 part of corn should be fed, and the proportion of skim milk should be reduced to about 1 or 1½ parts to 1 part of corn when the pigs weigh 150 pounds or more. Under these conditions, it can generally be figured that 100 pounds of skim milk is worth about half the price of a bushel of corn. The feeding value of buttermilk is similar to that of skim milk for pigs. Skim milk or buttermilk from cows that have not been tested and found to be free from tuberculosis should be pasteurized before being fed to pigs to prevent transmitting this disease.

Whey from cheese factories when fed to hogs has been found to be worth about half as much per 100 pounds as skim milk, or about the price of a peck of corn. Best results are usually obtained when whey is fed as a protein supplement to a corn or barley ration in combination with such feeds as linseed meal, cottonseed meal, or middlings.

Digester tankages, a byproduct of the packing industry used in hog feeding, are usually classified according to the percentage of protein they contain, which may range from 35 percent in the lower grade to 60 in the higher. Tankage is a good protein supplement to any of the cereal grains in balancing the ration. It is also high in mineral content and helps to supply the mineral deficiencies of the cereal grains. The grade of tankage is determined on the basis of the economy with which it furnishes a unit of protein. The fat in the tankage should be figured as equal in value to an equivalent amount of corn.

Fish meal is a byproduct of the fisheries industry. It is manufactured on both the Atlantic and Pacific coasts and has a wide distribution as a high-grade protein supplement in competition with tankage. Fish meal came into prominence as a protein supplement in this country about 1920. Its composition is somewhat similar to that of tankage but it is in addition a source of vitamins A and D. In summarizing a number of tests conducted at various State agricultural experiment stations comparing the value of fish meal with tankage as a protein supplement to the corn ration, Morrison (*819*) found fish meal to be superior for fattening hogs in dry lot. The difference was not so great for pigs on pasture as for pigs in the dry lot. The method of manufacture of fish meal is a determining factor in its nutritive value, the vacuum-dried product generally having a higher nutritive value than the flame-dried product made from the same raw material. Price will no doubt be the main factor in deciding which of the kinds of fish meal to use.

Shrimp meal, sometimes referred to as shrimp bran, is a good protein supplement produced in limited quantities. It consists of the dried heads and hulls of shrimp, a byproduct of the shrimp industry. The meal contains approximately 40 to 45 percent of protein. Experiments at the Louisiana Agricultural Experiment Station (*149*) show it to be equal or superior to tankage as a protein supplement, whether fed with or without other supplements. It is also cheaper in price per ton than tankage.

Cottonseed meal, a byproduct of the cotton industry, is a cheap source of protein when fed in limited quantities. It is deficient in calcium and vitamin A, but experiments at the Texas Agricultural Experiment Station (*458*) indicate that it may be fed in amounts up to 9 percent of the ration with little danger. Like linseed meal it can be used to best advantage mixed with tankage or fish meal. The addition of good-quality ground alfalfa hay to a cottonseed-meal ration supplies calcium and vitamin A and improves the quality of the ration.

Fifty pounds of tankage, shrimp bran, or fish meal, 25 pounds of cottonseed meal, and 25 pounds of ground alfalfa hay make an efficient protein mixture. Good results are obtained when the grains and protein supplement are placed in separate compartments of a self-feeder and the hogs are allowed free access to the feeds at all times.

Peanut meal, a byproduct of the peanut industry, is a good protein of plant origin. Because it is lacking in vitamins A and D and is low in calcium, these elements should be supplied in the ration through other feeds. Good results have been obtained in fattening hogs on pasture when peanut meal has been fed in the proportion of approximately 5 parts of corn and 1 part of peanut meal, supplemented with a good mineral mixture. For younger pigs it is advisable to combine peanut meal with tankage or fish meal to furnish protein of good quality. When peanut meal makes up half of the protein supplement for pigs on a corn ration in dry-lot feeding, the gains are usually slower and less economical than when either soybean or cottonseed meal is used.

Soybean meal (oil extracted), containing 35 to 42 percent of digestible protein, is an excellent protein supplement to the usual grains for growing and fattening hogs. It may be used as the sole protein supplement for hogs weighing 100 pounds or over, or it may be fed in combination with tankage or fish meal. Soybean meal is low in calcium and phosphorus, and a mineral mixture containing both of these elements should be available to hogs at all times. If home-grown soybeans can be exchanged for soybean meal at or near the same price per ton it is well worth the trade because the latter can be used more extensively in the ration.

Alfalfa meal made by grinding alfalfa hay is fairly rich in protein and minerals and is a good source of vitamins A and D. On account of its bulk it should not be fed as the sole protein supplement to fattening pigs, but it may be combined with other more concentrated proteins. Alfalfa-leaf meal has a higher protein and a lower crude-fiber content and is usually higher in price than alfalfa meal. In comparing the two from the standpoint of economy, the vitamin and mineral content should be considered in relation to the need of the hogs for these nutritive essentials. Alfalfa meal or ground alfalfa hay can be fed efficiently at a level of 5 or 10 percent of the total ration, or even 15 to 20 percent when the ration is balanced otherwise. As a home-grown protein supplement, the use of alfalfa meal may reduce the amount of high-priced protein feeds that must be purchased.

A number of suggested protein supplements composed of feeds of both animal and plant origin are shown in table 2. These supplements provide for the use of home-grown protein products, either wholly or in part. They may be fed in a definite proportion with the grain ration or mixed and fed in a self-feeder, giving the hogs free choice.

TABLE 2. *Suggested formulas for protein mixtures* [1]

Formula No.	Tankage	Linseed meal	Alfalfa meal	Cotton-seed meal	Soybean meal	Ground soybeans
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
1	50	25	25			
2	50		25	25		
3	25		25			50
4	25		25	50		
5	25		25		50	
6	30		35	35		
7	25		50		25	

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[1] Either fish meal or shrimp meal may be substituted for tankage in the above mixtures. Skim milk or buttermilk may be used instead of tankage. When used as the only protein supplement, 2 pounds of milk may be used to 1 pound of grain.

SELECTING THE RATION

Besides establishing fundamental facts about the nutritive requirements of swine, experimental work conducted by the agricultural experiment stations during the past 50 years has answered many practical questions about the selection of rations.

Not all the feed eaten by the hog is digested or utilized. The proportion utilized varies partly according to the kind of feed. To get a high degree of utilization, it is necessary for the most part to depend on specific combinations of feeds. Because of this fact, tables of feed analyses with coefficients of digestibility, biological values of proteins, and other expressions of nutritive value lack the degree of exactness of figures for the nutritive value of a specific ration used under specified conditions.

Results of experimental work indicate that as the percentage of fiber in the ration for fattening hogs is increased beyond a certain point, the rate of gain of the pig tends to decrease, while the amount of feed required to produce a unit of gain increases. A ration for good growth and fattening usually does not contain over 5 percent of fiber, although as much as 7 or 8 percent is sometimes fed without materially affecting the rate of gain.

The question of how much protein to feed is usually difficult to answer. Since proteins have varying biological values as building material for animal tissues, it may be best to supply an excess in the ration if the price of protein feeds is not too high in relation to other feeds. Generally speaking, the ration for pigs weighing 35 to 100 pounds should contain approximately 18 to 20 percent of protein; for hogs weighing 100 to 150 pounds, approximately 15 percent; and for hogs weighing 150 to 225 pounds, approximately 12 percent.

The choice of the feeds to be used in the ration will depend on what is available locally and comparative costs. There is no certain method of determining the feeds that will give best results without a definite comparison, which is not always practicable. Usually the feed that costs least per unit of protein is the one to use. For example, if 100 pounds of 60-percent-protein tankage costs $3 and 100 pounds of soybean meal containing 40 percent of protein costs $1.75, then a unit of protein in tankage would cost $3 divided by 60, or 5 cents a pound, while a unit of protein in soybean meal would cost $1.75 divided by 40, or 4.38 cents a pound. In this case the unit of protein is cheaper in soybean meal without regard to digestibility or biological value. These two factors vary with different combinations of feeds fed under different conditions. For example, the Wisconsin Agricultural Experiment Station found that the trinity mixture, composed of 50 parts of tankage, 25 parts of linseed meal, and 25 parts of alfalfa meal, by weight, when fed under certain conditions produced more economical gains than tankage fed as a sole supplement.

The need for minerals and vitamins can usually be met in a well-balanced ration through a judicious use of protein feeds and forage without recourse to special supplements. The cereal grains are low in minerals and contain less calcium than is needed for rapid growth. Protein supplements such as tankage, fish meal, and skim milk are relatively high in calcium and ordinarily furnish enough of this element. Phosphorus is usually found in adequate amounts in grains and protein supplements. Pastures likewise furnish minerals and vitamins to help correct the deficiencies of those elements lacking in the grain ration. When hogs are fed in dry lot there is more likelihood of a shortage of minerals and vitamins. In this case a mineral mixture may be kept available in small boxes or self-feeders to which the hogs have access at all times, or minerals may be fed in the grain ration at the rate of 1 pound of mineral mixture to each 100 pounds of feed mixture. The vitamins present in green pasture, legume hays, and yellow corn are generally considered sufficient to meet the requirements.

The tables in the article Composition of the Principal Feedstuffs Used for Livestock (p. 1065) should be consulted for data on general composition, including calcium and phosphorus, and for the digestible nutrients of the more common hog feeds as an aid in the selection of the more unusual feed combinations for compounding rations.

METHODS OF FEEDING

A number of different methods may be used in feeding hogs, including hand feeding, self-feeding, limited feeding, and hogging-down crops. It is not possible to say that any one system is the most practical under all conditions. In fact, the hog feeder may employ two or more methods. A brief description of the various methods will be given, but it will be for the individual to decide which best fits into his production program.

Years ago the hand-feeding system was used almost exclusively except as pigs were permitted to graze in the woods and fields. The results obtained by this method depend largely on the ability of the feeder to determine the amount to feed. Regularity is important, as the pigs become accustomed to the time of feeding—usually twice daily, morning and evening, although some feeders may give a noonday meal—and any great variation may tend to upset the digestive system. The feed is usually dry or in slop form and is mixed in definite proportions so that the hog has no choice, but must accept the mixture as a whole.

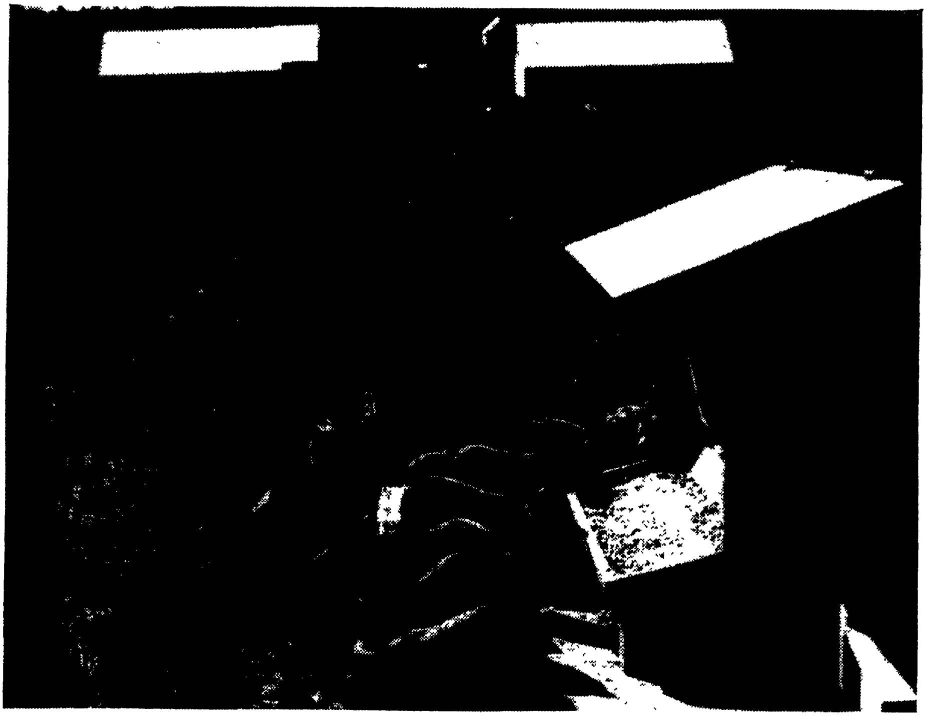

Figure 2.—Suckling pigs with access to a self-feeder containing supplementary feeds.

Since about 1920, self-feeding has come into prominence as an economical method. The hog is one animal that will not overeat when given unlimited access to large quantities of feed. The results of many experiments comparing hand feeding with self-feeding for growing and fattening hogs generally favor the latter method. Various aspects of rationing by the self-feeder method have been discussed by Evvard (*351*). Different feeds are generally placed in separate compartments of the feeder and the pig is allowed to balance its own ration (fig. 2). Generally speaking, the pig selects different feeds in the proportions that meet its needs for growth and development. The efficacy of the system is discussed in the article Nutritive Requirements of Swine in connection with the daily intake of total feed and protein by record-of-performance pigs (p. 714). Self-fed pigs eat smaller amounts at a time but eat many times during each 24 hours. The fact that they eat smaller amounts at a feeding may lead to less waste in the assimilation of food and account for the more economical use of feed. A self-fed pig also seems to be more satisfied, seldom grunting or squealing, whereas the pig that is hand fed is usually squealing for feed at various intervals between feedings. Aside from the fact that self-fed pigs usually gain rapidly, the saving in labor under this system is a point especially in its favor.

If it is desired to feed a certain combination of grain and protein supplements, the feeds may be mixed in definite proportions and the dry feed placed in the self-feeder where the hog will have an opportunity to eat the amount it desires at any time. Though many combinations of feeds may be used, a few are suggested in table 3 for different classes of hogs, fed by either the hand-feeding or the self-feeding method, on a full grain allowance.

TABLE 3.—*Suggested feed combinations for various classes of hogs*

Class of hogs	Corn	Barley	Wheat	Oats	Rye	Grain sorghum	Tankage or fish meal[1]	Cottonseed meal[2]	Linseed meal[2]	Alfalfa meal	Soybeans[2]	Soybean meal
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Growing—weaning to 100 pounds (dry lot)	80	----	----	----	----	----	10	----	5	5	----	----
	----	85	----	----	----	----	5	5	----	5	----	----
	----	----	90	----	----	----	4	2	2	2	----	----
	65	----	----	20	----	----	5	----	----	5	----	5
	80	----	----	----	----	----	7	----	----	5	8	----
	----	----	----	----	----	85	5	5	----	5	----	----
Growing—weaning to 100 pounds (on pasture)	----	40	25	25	----	----	5	5	----	----	----	----
	55	----	----	----	30	----	5	----	5	----	----	5
	----	90	----	----	----	----	5	----	5	----	----	----
	85	----	----	----	----	----	9	----	6	----	----	----
	30	40	20	----	----	----	5	----	----	----	----	5
	----	92	----	----	----	----	4	----	4	----	----	----
Fattening hogs over 100 pounds (dry lot)	----	45	25	25	----	----	2	3	----	----	----	----
	45	----	----	----	45	----	5	----	5	----	----	----
	89	----	----	----	----	----	5	----	----	----	6	----
	82	----	----	----	----	----	4	----	4	10	----	----
	21	50	20	----	----	----	5	----	----	4	----	----
	----	----	----	30	----	62	4	----	----	----	----	4
Fattening hogs over 100 pounds (on pasture)	47	----	----	----	47	----	6	----	----	----	----	----
	----	----	----	----	----	92	4	----	4	----	----	----
	90	----	----	----	----	----	5	----	----	----	----	5
	70	----	----	25	----	----	5	----	----	----	----	----
	----	96	----	----	----	----	4	----	----	----	----	----
	20	50	25	----	----	----	2	----	3	----	----	----
	87	----	----	----	----	----	3	----	----	----	10	----
Brood sows and boars	88	----	----	----	----	----	6	----	3	3	----	----
	65	20	----	----	----	----	5	----	----	10	----	----
	65	----	----	30	----	----	5	----	----	----	----	----
	----	----	----	----	----	82	4	4	----	10	----	----
	----	----	90	----	----	----	5	----	----	5	----	----
	----	62	----	30	----	----	3	----	----	----	----	5
	85	----	----	----	----	----	2	----	----	5	8	----

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[1] Shrimp meal may be substituted for tankage or fish meal in the above mixtures. Skim milk or buttermilk may be substituted for tankage or fish meal. Approximately 11 pounds of skim milk or buttermilk will replace 1 pound of tankage.

[2] Linseed meal, soybeans, or cottonseed meal may be used interchangeably.

Figure 3.—Pigs hogging down corn and soybeans. This method of feeding saves labor and distributes fertility over the land.

Limited feeding, in which less than a full daily ration is fed, may be employed when the seasonal feed supply is limited until a new crop is available. Pigs may also be limited in feed when it is desirable to hold them for a certain market. In the case of feeder pigs, the limiting of grain on pasture leads to a greater utilization of forage crops and aids in economical production.

Experiments were conducted by the Department on the effect of limiting the feed allowance to approximately three-quarters and one-half of full feed to pigs starting at 65 pounds in weight and fed to a weight of 200 pounds. The quantity of feed required to produce a unit of gain was generally smaller than on full feeding, although the rate of gain was slower. Pigs on limited feed have less opportunity to store fat, and the meat tends to have a higher proportion of lean than that of full-fed pigs. From the practical standpoint the feeder must decide whether the increased labor necessary under this system might more than offset the saving of feed. Better results are usually obtained when the pig is well grown to a weight of approximately 65 to 75 pounds before the period of restricted feeding begins.

The method of hogging down crops is practiced quite generally in many sections. Corn is the principal crop used and the hogs are usually turned into the field when the corn is in the dent stage. This method saves the labor of harvesting the crop and also has the advantage of scattering the manure over the land (fig. 3). Hogs should not be given too large an area to work over at a time or there may be an excessive waste of grain. A self-feeder containing a protein supplement may be placed in the field, or the supplement may be hand-fed daily to help balance the ration. Usually a short period of feeding in dry lot is required to finish the hogs before they are marketed. The practice of hogging down small grains is not generally followed, although such crops as rye, barley, and oats are sometimes harvested in this manner. There is usually a larger waste because of the small size of the seeds. Supplemental protein and mineral feeds should be given when small grains are hogged down. In the South, peanuts, sweetpotatoes, and other root and tuber crops are frequently harvested by hogging down.

PASTURES

Pasture crops are important in the economical production of hogs. They not only reduce the cost of needed protein, minerals, and vitamins but are a big factor in controlling parasitic infestation if a system of pasture-lot rotation is used. Pigs cannot be grown and fattened economically on forage crops alone, but these crops are an important adjunct to a good grain ration (fig. 4). The saving in the number of pounds of grain required to produce 100 pounds of gain when pigs are on pasture varies considerably. It is estimated that on the average good-quality pasture saves approximately 15 percent of the grain concentrate per unit of gain and speeds up the rate of gain in comparison with hogs fed in dry lot.

Permanent pastures do not give the most economical returns unless they are supplemented by temporary pastures. A combination of the two is a valuable asset. When properly planned they can supplement each other and furnish good-quality grazing at practically all seasons of the year.

The plants used most extensively for permanent hog pastures are alfalfa, red clover, alsike, white clover, bluegrass, orchard grass,

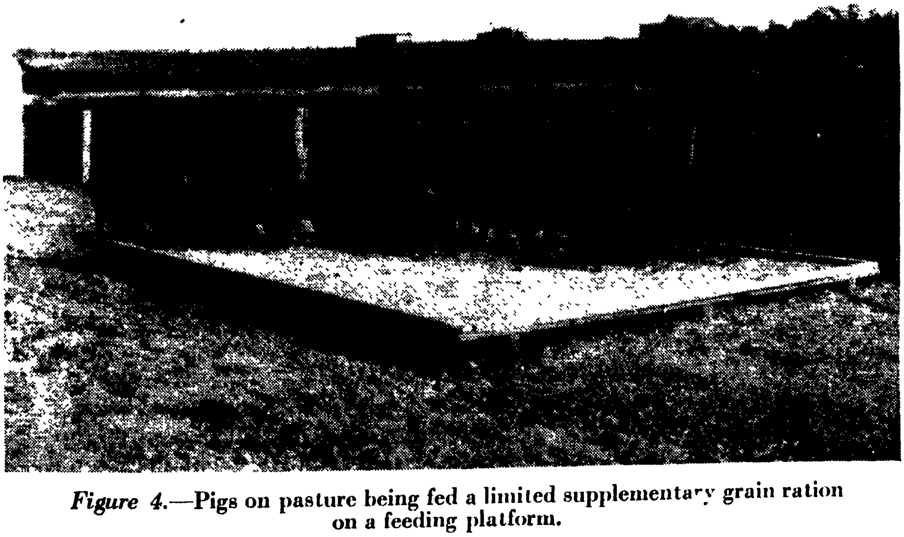

Figure 4.—Pigs on pasture being fed a limited supplementary grain ration on a feeding platform.

lespedeza, and carpet grass. The most common temporary-pasture plants are rape, rye, oats, wheat, soybeans, cowpeas, and field peas. Seeding for temporary pastures should be timed to furnish grazing for short intervals when permanent pastures are in a dormant or resting state. When given a period of rest after close grazing, temporary pastures may make sufficient regrowth to furnish a second grazing period before the field is plowed for the next crop. The rate of seeding for temporary pastures is usually much heavier than for a grain crop.

Legume crops such as alfalfa, the clovers, and rape usually yield the greatest returns in pork production. As a general rule pigs grazed on a good legume pasture when on full feed require approximately half as much concentrated protein supplement as pigs in dry lot. If the amount of grain on pasture is limited, the pigs will consume a greater quantity of forage and possibly require only 30 to 40 percent as much concentrated protein supplement as hogs in dry lot. As the hog grows it will be able to consume greater amounts of forage, thus progessively decreasing the amount of protein supplements needed.

Since there are so many different factors to consider in planning a pasture crop-rotation system for hogs it is best to consult the State agricultural experiment station as to the pasture crops best adapted to a particular region, the time and rate of seeding, and the stage of growth at which the crop should be pastured.

FEEDING FOR SPECIAL CONDITIONS

SUCKLING PIGS

The suckling pig during the first 2 or 3 weeks obtains all its nutrients from the mother's milk. When the pig is approximately 3 weeks of age it will begin to take additional feed. Feeds of a protein nature such as skim milk or tankage, if made available in a creep, will give the needed stimulus to faster growth and produce a larger pig at weaning time.

GROWING AND FATTENING PIGS

It may be more profitable at times and under certain conditions to limit the feed of growing pigs to prevent fattening before the fattening period begins. When full feeding is practiced, pigs should be fed liberally on a well-balanced ration. Following weaning, the young pig should receive a ration that supplies a large amount of protein. Protein needs cannot be met by any other nutrient, and if sufficient protein is not present in the ration, the needs will be supplied from the tissues of the body and growth will be retarded. The pig is able to retain and build into muscle tissue a large part of the protein taken from the feed. As it grows older the percentage of protein stored in the body decreases. After growth has stopped and the muscles and organs have reached their full development, little protein is stored. It is important, therefore, that the ration of the young growing animal furnish the proper nutrients to utilize to the fullest extent this early efficiency in transforming food into body tissue. Pasture and forage crops play an important part in producing cheap gains on growing pigs.

After the pig attains its growth, the demands for fat production, which are supplied largely by carbohydrates, are most important. Concentrates must be supplied, since the hogs cannot consume enough pasture or cured forage to fatten them. Fattening pigs on full feed require approximately 5 pounds of feed daily per 100 pounds of live weight up to 100 pounds in weight. From 100 pounds to a finished weight of 225 pounds, pigs on full feed require about 4 pounds of feed daily for each 100 pounds of live weight. On the average about 400 pounds of feed are required to produce 100 pounds of gain from weaning age to approximately 200 pounds weight. About 360 pounds of this is corn and 40 pounds tankage, fish meal, or the equivalent. On this basis, pigs weighing 35 pounds at weaning and gaining 165 pounds would require 594 pounds of corn and 66 pounds of protein supplement, or a total of 660 pounds of feed from weaning to a market weight of 200 pounds. An additional 100 pounds of feed per pig raised should be added to feed the sow and litter during the suckling period.

Hogs fattened in dry lot require a protein supplement for most efficient results. When hogs are fattened with access to a good pasture, the addition of a protein supplement increases the rate and economy of gains.

THE BREEDING HERD

Pigs that are to be developed for the breeding herd should be fed to get the maximum growth and development without becoming too fat. Both gilts and boar pigs should be fed a ration in which protein makes up at least 12 to 14 percent of the total feed in order to make the maximum development. The pigs should have access to good pasture in summer and to good-quality alfalfa hay or alfalfa meal in winter. Pigs on good pasture may be fed approximately a 3-percent grain ration (3 pounds of feed per 100 pounds live weight daily). Gilts of large type may even be self-fed with the fattening hogs until they reach a weight of approximately 200 pounds without becoming too fat for breeding.

The protein requirements of the boar may be considered the same as those of the sow of equal weight. The young growing boar during the period between breeding seasons needs protein for growth in addition to the requirements for maintenance. Just prior to and during the breeding season the protein part of the ration should be increased to provide for the increased activity during this period.

THE GESTATION PERIOD

The protein, vitamin, and mineral requirements for normal reproduction may be met cheaply if the sows are given access to fall wheat or rye pasture or any other kind of green pasture plus a mineral supplement. When green pasture is not available a rack supplied with green, leafy legume hay, such as alfalfa, soybean, or cowpea hay, will provide proteins, minerals, and vitamins of desirable quality.

Gilts are usually bred at 8 to 8½ months of age to farrow their first litter when 1 year old. During the gestation period, the gilt will usually make better use of her feed than at other times. A gilt carrying her first litter should be furnished with sufficient protein to meet the needs of maintenance and growth in addition to the needs of the growing embryos. For this reason gilts should receive a little more protein daily than old sows. The gilt ration should contain at least

12 to 15 percent of protein of good quality, including a protein of animal origin. A protein reserve should also be built up in the body to provide for the demands of the lactation period when the production of milk for the litter often requires more protein than the sow is able to digest from her daily ration.

The ration for the mature sow during the gestation period should contain at least 10 to 12 percent of protein to meet the needs for maintenance and body repair, the development of the growing embryos, and the lactation period. Since old sows need no protein for growth, they can be fed a larger amount of carbohydrate feeds, which in general are cheaper than the protein supplements.

A ration that contains corn, protein supplement, and a mineral mixture is suggested for the gestation period. The protein supplement may consist of 50 parts of tankage, 25 parts of linseed meal, and 25 parts of alfalfa-leaf meal. To 100 pounds of this mixture may be added 5 pounds of a mineral mixture composed of equal parts of ground limestone, steamed bonemeal, and common salt. A sow should be fed to gain ½ to 1¼ pounds a day during the gestation period, depending on her condition when bred. Gilts may be fed a ration composed of 7 parts of corn and 1 part of protein and mineral supplement, while old sows may be fed a ration of 8 parts of corn and 1 part of protein and mineral supplement. These mixtures may be fed at the rate of 1½ to 2 pounds daily per 100 pounds live weight, depending upon the condition of the sow. In addition sows should have access to good-quality legume hay in a rack if pasture is not available.

SOWS SUCKLING LITTERS

Sows suckling their litters need a liberal ration containing feeds rich in protein and minerals. If possible they should also have access to good pasture. If this is not available, the ration may contain 5 to 10 percent of good-quality alfalfa hay. Feeds that will furnish a heavy milk flow are desirable so the pigs will get a good start in life. At no time do pigs make as economical gains as when they suckle their dams. A sow on full feed following farrowing will need 3 to 5 pounds of feed daily per 100 pounds live weight, depending on the number of pigs in the litter.

PRESENT-DAY PROBLEMS IN SWINE FEEDING

Experiments in the past developed new methods of feeding, the use of new feeds, and efficient combinations of different feeds to produce economical returns, but present knowledge is limited on many problems of swine feeding. The chemistry of proteins is a field of research that has great possibilities. Information on the amounts of different amino acids in various feeds is fragmentary. More knowledge in this field may lead to entirely different feed combinations or levels of feeding from those used today.

Research in the field of mineral metabolism offers possibilities for refinement of present knowledge. Though past work has thrown much light on the part played by calcium, phosphorus, copper, iron, and iodine in metabolism, little is known of the interaction of such elements as magnesium, manganese, cobalt, and zinc.

Although studies on certain vitamins are well advanced in the case of small laboratory animals, and to a lesser extent with human beings, their application to the hog is not so far advanced. However, within a comparatively short period pure chemical compounds of a number of vitamins, including riboflavin, nicotinic acid, thiamin, and ascorbic acid, have become available. This simplifies vitamin research by aiding in making up synthetic diets in which the effect of the presence or absence of a single nutrient can be determined.

The relation of nutrition to fertility and the size and vigor of the litter is a field that deserves special attention. What are the factors that affect milk secretion and influence the quality and quantity of milk from the standpoint of the growth and development of the young suckling pig? Although this problem has received much attention in the case of dairy cows, little is known about it in relation to the pig.

Investigation of the nutritive value of different pasture grasses in different stages of growth and the extent to which they may be used in developing the most efficient type of ration offers opportunity for improvement in swine feeding.

FEEDING PROBLEMS WITH SHEEP

by Damon A. Spencer[1]

THOUGH this article deals briefly with some of the nutritive requirements of sheep, in the main the author is concerned with practical feeding. He tells about the fattening of lambs, hothouse lamb production, "flushing" ewes, feeding the farm flock, feeding on the range, poisonous plants—and finally, the relation of nutritional research to the problems of the sheepman.

SHEEP are naturally adapted to grazing on pastures and ranges that supply a variety of forage plants (fig. 1, *A* and *B*, fig. 2, *A*). They do best on forage that is short and fine rather than high and coarse (*238*, *749*).[2] They will eat considerable quantities of brush, but they prefer chiefly choice grass and legumes and lush, palatable weeds (*222*). It is seldom profitable to feed grain to breeding sheep or even to suckling lambs when they can have an abundance of succulent grazing forage (*751*). In some environments flocks can be kept in good thrifty condition and lambs can be raised to the marketing stage without the feeding of any grain (*474*). One hundred pounds of grain in a year for one ewe and her lambs is the maximum quantity that is likely to be profitable.

Deep snows, extreme droughts, overstocked pastures and ranges, and other conditions that adversely affect grazing make it necessary to feed sheep from the stack, mow, and bin. Sheep are fond of good roughage and they are able to make good use of it. They can obtain most of their needs for protein, calcium, and vitamins, especially vitamins A and D, from an abundance of well-cured legume hay (*819*). Good legume roughage provides ample nutrients for breeding ewes during the winter up to about a month before lambing time. From that time until pasture is abundant extra nutrients should be provided in the form of concentrates, such as a mixture of equal parts by weight of oats, corn, and bran, together with about 10 percent by weight of cottonseed or linseed meal. The rapid growth of the unborn lambs during the last month of pregnancy may justify a daily allowance of

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[2] Italic numbers in parentheses refer to Literature Cited, p. 1075.

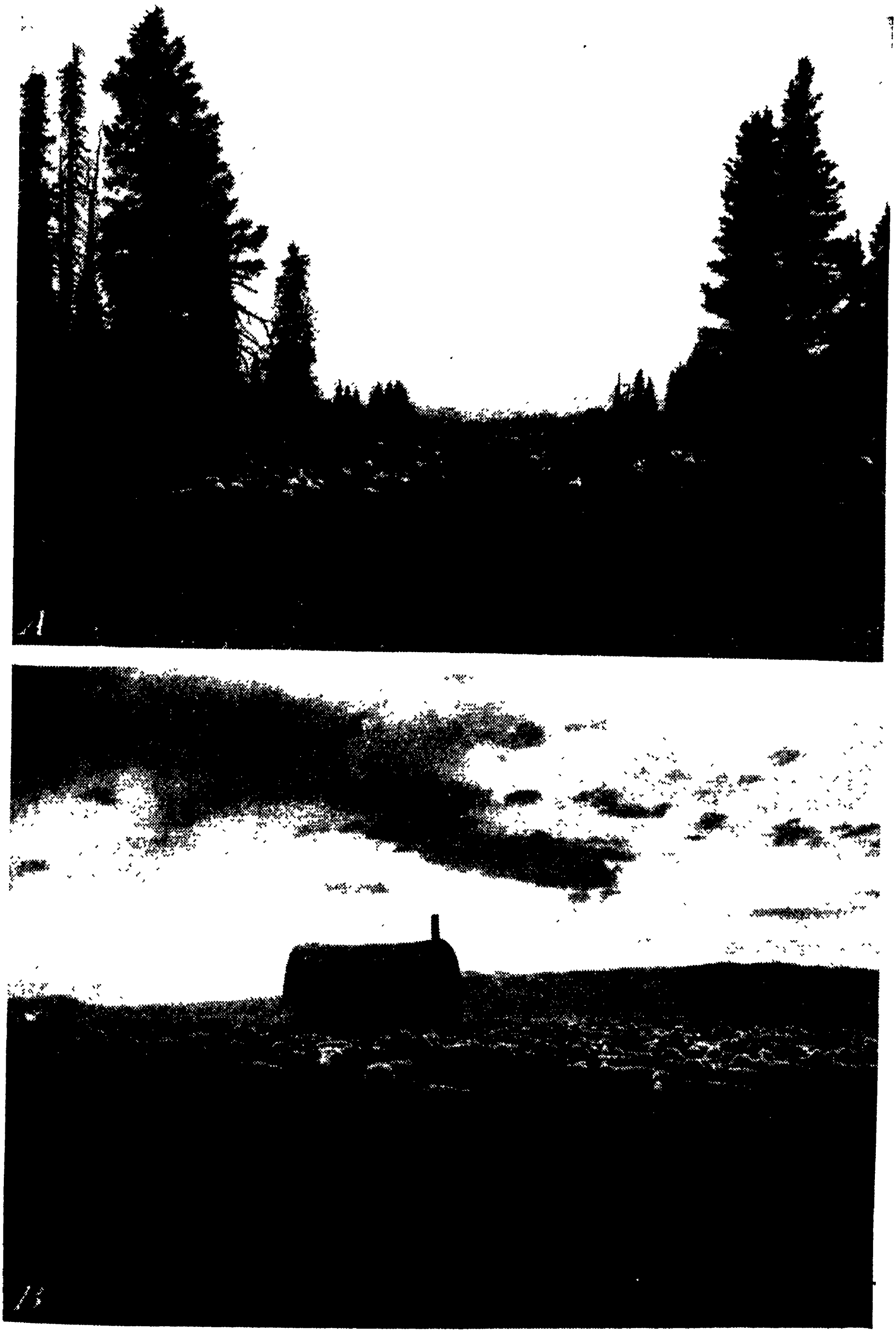

Figure 1.—*A*, Sheep grazing on the high summer ranges of the Targhee National Forest, west of Yellowstone Park, in Idaho. *B*, A band of sheep at sundown on the spring-fall sagebrush range of the United States Sheep Experiment Station, Idaho. The camp wagon is the sheep herder's home.

one-fourth to one-half pound of this or a similar mixture of concentrates for each ewe until lambing and a gradual increase after lambing up to three-fourths of a pound or possibly 1 pound a day until pasture is abundant. The nutritive requirements of ewes nursing lambs are, in principle, like those of dairy cows in milk (*838*). The ewes need much more protein and digestible nutrients than before lambing.

Since wool fibers are composed of protein, sheep need feeds that contain a liberal supply of this nutrient to produce a good wool crop. Wool is rich in the sulfur-containing amino acid cystine, but there appears to be sufficient cystine in ordinary rations that are otherwise satisfactory for sheep (*819*).

In some sheep-producing regions farmers and ranchmen have difficulty in growing adequate supplies of legume hays such as alfalfa, clover, or soybeans, and they are compelled to feed timothy or native grass hay, straw, or corn stover. These nonleguminous roughages may be supplemented with such protein-rich concentrates as linseed meal, cottonseed meal, soybean-oil meal, or soybeans at the rate of about one-quarter to one-half pound per ewe per day. Timothy hay cut in the early stage of maturity or before full bloom is much more satisfactory for sheep than when it is cut fully ripe (*90, 91*).

Sheep are particularly fond of salt and consume considerably more per 100 pounds of live weight than do cattle. Breeding sheep may consume nearly one-half ounce per head daily and fattening lambs from one-fifth to one-fourth ounce. When sheep are accustomed to salt it is best to let them have access to it in suitable containers so that they may take as much as they desire (*198*). On western ranges in areas where there is considerable alkali, sheep are allowed no salt other than that which they get in the alkali. This seems to be safe in cases where the alkali contains at least 85 percent of salt.

Calcium supplements must be fed to sheep when their roughage consists only of nonleguminous plants grown on soils low in calcium. They may be fed about one-quarter ounce or more per head daily of ground limestone or some other calcium supplement in the form of a mixture of two parts calcium supplement to one part common salt by weight (*382*). If the roughage, on the dry basis, is at least a third good legume hay or other legume forage, this third should supply plenty of calcium. If there appears to be need for a supplement containing phosphorus, this may ordinarily be fed in the form of a mixture of 2 parts of bonemeal to 1 part of common salt by weight. In the feed lots, however, phosphorus is less apt to be lacking in the usual sheep rations than is calcium (*819*).

Iodine may have to be fed to ewes in districts where there is trouble with goiter in newborn lambs (*88, 354*). In such cases the ewes should be fed iodized salt at least during the last half of pregnancy. An allowance of one-twentieth of a grain of potassium iodide per head daily is enough to prevent goiter. It is safest not to allow more as too large doses may be injurious. Experimental evidence indicates that other minerals, including iron, copper, sulfur, cobalt, and potash salts, need not be added to the usual rations for sheep (*223*). In some areas not yet important for sheep raising there may be a deficiency of one or more of these minerals in the forage plants great enough to interfere with the normal development of sheep.

The most recent experimental findings on vitamin requirements of sheep indicate that vitamin A is the only one that is likely to be lacking in the usual sheep feeds, and this deficiency is generally found in such roughage as cereal straw, poor-quality hay, or cottonseed hulls. Early-cut, well-cured hay is high in vitamin A, or rather carotene, and if such good hay makes up a substantial part of the ration there should be sufficient vitamin A for sheep (*498*).

The requirement of sheep for vitamin A is about the same per unit of body weight as that of other farm animals. Experimental results with the usual feeding practices, however, indicate that it is necessary to feed sheep winter roughage of better quality than that sometimes used for breeding cows. This may be due to the fact that sheep have lower reserves of vitamin A than cows when they go into the winter feed lots (*87*).

Under ordinary conditions it is essential to furnish sheep with plenty of fresh water (*271*). On dry feed ewes drink from 1 to 1½ gallons a day and fattening lambs slightly more than 1 quart up to 2 quarts a day. When succulent feeds are provided, sheep drink less than when they are on strictly dry feeds, and when the weather is hot they drink more than when it is cool or cold. During late fall, winter, and early spring range sheep often derive their principal water intake from snow.

THE FATTENING OF LAMBS

All lamb producers in regions that provide pastures and ranges yielding the abundance of succulent, nutritious forage essential for early fattening (*560*) desire to produce milk-fat lambs—that is, lambs that are sufficiently finished to be slaughtered at weaning time. Many lambs, however, are raised on pastures and ranges that are not adequate for finishing at the weaning age of 4 to 6 months, and even on the best forage some mutton-type lambs and a large proportion of the lambs of the fine-wool type cannot be finished by weaning time. For these reasons a rather large proportion of the lamb crop of the United States must be fattened to a slaughter finish after weaning (fig. 2, *B*). The nutritive requirements of these feeder lambs are therefore an important problem in the sheep-feeding enterprise.

Corn is the grain most used in the United States as the chief fattening concentrate for lambs, but in some regions barley or sorghum grain is more readily available and is fed in the place of corn. Oats have been successfully substituted for corn in lamb-fattening rations (*631*). When available at reasonable prices, corn and alfalfa hay are preferred by most lamb feeders as the basal lamb-fattening ration (*968*). The primary needs are a fat-producing concentrate rich in carbohydrate and a roughage, such as legume hay, relatively rich in protein (*1063*).

When silage, especially corn silage, is available at reasonable cost, it may be economical to include it in the lamb-fattening ration together with a protein-rich meal such as cottonseed or linseed (*613*). Such a ration may consist of 7 parts of corn by weight and 1 part of cottonseed meal, plus corn silage and clover hay (*473*). If lambs on full feed are fed twice a day as much of the mixture of corn and cottonseed meal as they will clean up by the time they leave the trough, as much

Figure 2.—*A*, A farm flock on pasture in Virginia; *B*, lambs in a Colorado feed lot, at grain troughs on the left and at hay racks in other parts of the lot.

of the corn silage as they can clean up in about an hour, and as much hay as they will consume by the next feeding time, the daily allowance per head will be approximately 1⅓ pounds each of concentrates, silage, and hay, or a total of about 4 pounds of feed a day (*631*). Such a ration would approximate the requirements of normal lambs entering the feed lot at an initial average body weight of about 60 to 65 pounds and finishing in about 80 to 90 days at average final live weights of 90 to 95 pounds at the feed lot (*768*, *1196*).

Such carbohydrate-rich concentrates as wheat, rye, or beet pulp may be fed as partial substitutes for the more usual corn, barley, oats, or sorghum grains (*594*, *734*). The prices of these various fattening feeds would have to be considered in determining whether it would be economical to feed them (*790*). Corn is regarded as the most efficient feed for fattening lambs, but normally the other carbohydrate-rich feeds mentioned are at least 80 to 90 percent as efficient as corn when calculated on the basis of dry-matter content.

Fattening lambs can utilize silage made from plants other than corn—for example, silage made from sorghum, peas and oats, pea vines, and corn and soybeans. Plants should be cut when they are not too green and immature if they are to make the best silage for lambs. This is especially true of sorghum. Other succulent feeds suitable for fattening lambs are turnips, mangels, rutabagas, wet beet pulp, beet tops, cabbage, and cull potatoes, but these contain more water and less solids than the silages mentioned (*819*).

FEEDING FOR HOTHOUSE LAMB PRODUCTION

Hothouse lambs are born in the fall or early winter and finished for slaughter as suckling lambs at the age of about 2 to 4 months at live weights of 40 to 60 pounds, or even less than 40 pounds if they are well finished. The term "hothouse" is used because such lambs are produced during an unusual season of the year, though not necessarily in quarters heated by a stove or furnace. If lambs are to be finished at such early ages and light weights, they must have the inherent capacity to develop and fatten rapidly, and their feeds and the feeds for their mothers must be of excellent quality. Hothouse lambs that measure up to the exacting requirements of the enterprise are often the offspring of Southdown rams and Dorset or Dorset-Merino ewes.

The mothers of hothouse lambs require choice legume hay and grain, and it usually pays to include a succulent feed in their rations so that they may produce plenty of milk. A good combination of feeds for such ewes is a concentrate mixture of 5 parts corn, 2 parts oats, 2 parts wheat bran, and 1 part linseed meal by weight, plus corn silage and well-cured, second-cutting alfalfa hay or similar feeds. The daily allowance per ewe varies, but when the lambs are 1 or 2 weeks old the ewes nursing them should be able to use to advantage about 1 to 1½ pounds of the concentrate mixture, 2 to 3 pounds of corn silage, and 2 to 3 pounds of alfalfa hay a day per head. They should be given as much concentrate as they will clean up before they leave the trough, as much silage as they will clean up in about an hour, and as much hay as they will clean up by the next feeding time.

Hothouse lambs should be fed in a creep (*216*) as soon as they will nibble at grain and roughage, which they will normally begin to do when they are about 2 weeks old. In order to get them to consume maximum quantities, only the very choicest feed should be offered and there should be nothing but fresh feed in the troughs and racks. The corn for the young lambs should be cracked and the oats crushed. Otherwise the concentrate mixture may be the same as that for the mother; that is, 5 parts cracked corn, 2 parts crushed oats, 2 parts wheat bran, and 1 part linseed meal, by weight. The alfalfa hay should be as leafy, bright, and excellent as possible and the silage the best available and free from any mold. The quantity of the feed consumed by the lambs will naturally increase as they become older. It is safe, however, to let them have as much as they will clean up each day. Any feed left over at the end of the day should be removed from the troughs and racks and fed to the older sheep.

"FLUSHING" EWES TO INCREASE LAMB YIELDS

The practice of extra feeding at breeding time to increase the number of twins produced by ewes is called flushing. This has proved to be profitable in the case of ewes, and of lambs through the suckling period, in regions that provide plenty of nutritious and succulent feed at reasonable cost. Good, nutritious pasture, when it is free from excess moisture which would cause it to be "washy," has been found effective and normally the most economical source of feed for flushing ewes. In case an abundance of such pasture is not available, however, corn, oats, wheat bran, and other grains may be used (*732*). Effective flushing has resulted from feeding about one-half to three-fourths of a pound of grain per ewe daily along with rather sparse forage of ordinary quality. Experiments by the Bureau of Animal Industry show that to flush ewes successfully they must be sufficiently well fed to gain at a rate of at least 1 pound a week per ewe during the breeding season (*750*).

FEEDING SHEEP IN FARM FLOCKS

In the eastern half of the United States and in the irrigated valleys and dry-land farming communities of the West, sheep are kept in small or moderate-sized flocks of about 20 to 100 head, or in some instances as many as 200 to 300. Most farm flocks are maintained under conditions that make it economical and practical for the breeding sheep to glean much of their feed from stubble and stalk fields in the fall before rains injure the feeding value of the gleanings. Normally, after these feeds have been used, clover and grass pastures are grazed. In regions where winters are open a heavy stand of well-cured bluegrass will help considerably to carry the flock through the winter in good condition. Green pastures of rye or wheat in late fall will provide succulent feed and furnish exercise for the flock. In the South, velvetbeans will be found a great help in carrying the flock into January (*751*).

In winter the feeding of the farm flock should be such as will produce vigorous lambs and keep the wool strong and in good condition. Leguminous hays, straws, and cornstalks usually form the main part of economical winter rations. Clover, alfalfa, soybean, or cowpea hay, if of good quality, may be used as the sole feed until near lambing time, from 4 to 5 pounds per ewe daily being sufficient for ewes weighing less than 150 pounds (*238*). Oat and wheat straw are better than rye or barley straw. Cornstalks placed where the sheep can eat off the leaves may be used as a part of the roughage ration. If the ration is made up largely of cornstalks or straw a protein concentrate should also be used. Timothy hay is not a good sheep feed unless it is cut when immature or just as it is beginning to bloom (*89*). As timothy hay is more easily grown than legume hays in much of the farm-flock territory many farm sheep are fed timothy either alone or mixed with clover hay. For this reason it is worth while to emphasize the importance of cutting timothy when immature if it is intended for sheep.

Succulent feeds such as silage or roots are desirable to keep ewes in good health, but they should be fed with some hay. When corn silage is fed to sheep it should be from well-matured corn, and great care should be exercised to avoid spoiled, frozen, or moldy silage. It is not advisable to feed ewes more than 3 pounds of silage per head daily. Turnips should be used sparingly for ewes until after lambing (*931*).

Each of the following rations contains approximately the quantity of the various nutrients required daily for pregnant ewes weighing from 110 to 140 pounds when in the dry lot:

(1)

3 pounds alfalfa or soybean hay
2 pounds corn silage
½ pound shelled corn

(2)

3 pounds alfalfa hay
2 pounds corn stover (edible portion)

(3)

3½ pounds alfalfa or clover hay
2 pounds corn silage

(4)

2 pounds oat straw
2 pounds corn silage
¾ pound shelled corn
¼ pound linseed meal

Where ewes can run on wheat or rye pasture during the winter they should also receive some dry or concentrated feed. Silage or roots are not desirable when the forage of the pasture is soft or green (*90*, *91*). One-half pound of cottonseed meal contains the daily requirement of protein for a pregnant ewe. When price suggests the heavy use of this concentrate, the other feeds of the ration should be rich in carbohydrates. It is best to limit the quantity of cottonseed meal to one-fourth pound per head daily, with a good selection of other feeds (*238*).

During late spring, summer, and early fall, farm sheep in most regions can obtain most of their feed requirements from good pasture (*208*). In the absence of good pasture it may be necessary to feed them as suggested for the winter period. The quantity of feed should be increased for ewes nursing lambs.

Rams may be fed the same kinds of feed as ewes but in slightly larger quantities. They need a good allowance of relatively high-quality feed just before and during the breeding season, when pasture is not available. After the breeding season, even before there is good pasture, they can be fed less grain and more roughage. The roughage does not need to be of more than fair quality to keep vigorous, mature rams in thrifty condition.

FEEDING RANGE SHEEP

In the western half of the United States a large majority of the sheep are produced in range bands varying in size from a few hundred to more than 2,000 head, but usually containing between 1,000 and 2,000 (fig. 3). They subsist largely on the natural forage of the range, but deep snow, drought, and scanty forage on overgrazed or inferior range make it necessary at times to feed hay and concentrates. Mineral deficiencies are serious problems in some areas where phosphorus, calcium, or iodine may be so inadequate as to necessitate the feeding of these minerals with salt as already suggested (*198*).

Many forage plants of the western range country cure while standing and provide nutritious feed during the fall and winter. For this reason range sheep can subsist on standing forage during the cold weather better than is generally possible for sheep in the farming regions. Range sheep also browse a great deal in cold weather and utilize rougher feed then than at any other time of the year. Many range sheep producers make a practice of feeding some concentrate in the winter and provide an extra supply of feed that may be used during extremely cold and stormy periods (*222*).

Alfalfa hay is the standard winter roughage for western range sheep in feed lots, but some native hay is fed when alfalfa is not available. If mature sheep are in thrifty condition when they are brought into the feed lot, grain is not usually fed with alfalfa hay, but when native hay is fed a protein concentrate, such as cottonseed cake, is desirable (*599*). Under the usual range conditions protein concentrates can be fed in the form of cake with greater economy and facility than in the form of meal (*598*). When alfalfa hay is the only feed provided, about 4 or 5 pounds will be required per ewe daily. A little less than this will be sufficient when grain is also fed. When conditions permit it may be desirable and economical to feed a small quantity of hay and let the sheep graze each day.

Breeding rams may be wintered on roughage and a small quantity of grain, as it is unnecessary to fatten them. A daily allowance of 5 to 7 pounds of fair alfalfa hay, depending on the size of the ram, and 1 pound of whole oats makes a good winter ration for rams in the western range country (*222*).

When shed lambing is practiced and the lambs are to be born before range forage would furnish good grazing, breeding ewes should receive some grain for about 3 weeks or a month before lambing. Whole oats at the rate of one-half pound a ewe per day makes a good grain ration, but corn, wheat, barley, and various grain mixtures have been successfully fed. Some corn silage, beet pulp, and comparable feed may be fed in limited quantities of 1 or 2 pounds daily per ewe before lambing and in more liberal quantities afterwards. These help to stimulate the milk flow. At this time the best quality of hay is needed.

The following rations are suggested for range ewes:

Ration before lambing	
Alfalfa hay	4 pounds
Whole oats	½ pound

Ration after lambing	
Alfalfa hay	5 pounds
Corn silage	2½ pounds
Whole oats	¾ pound

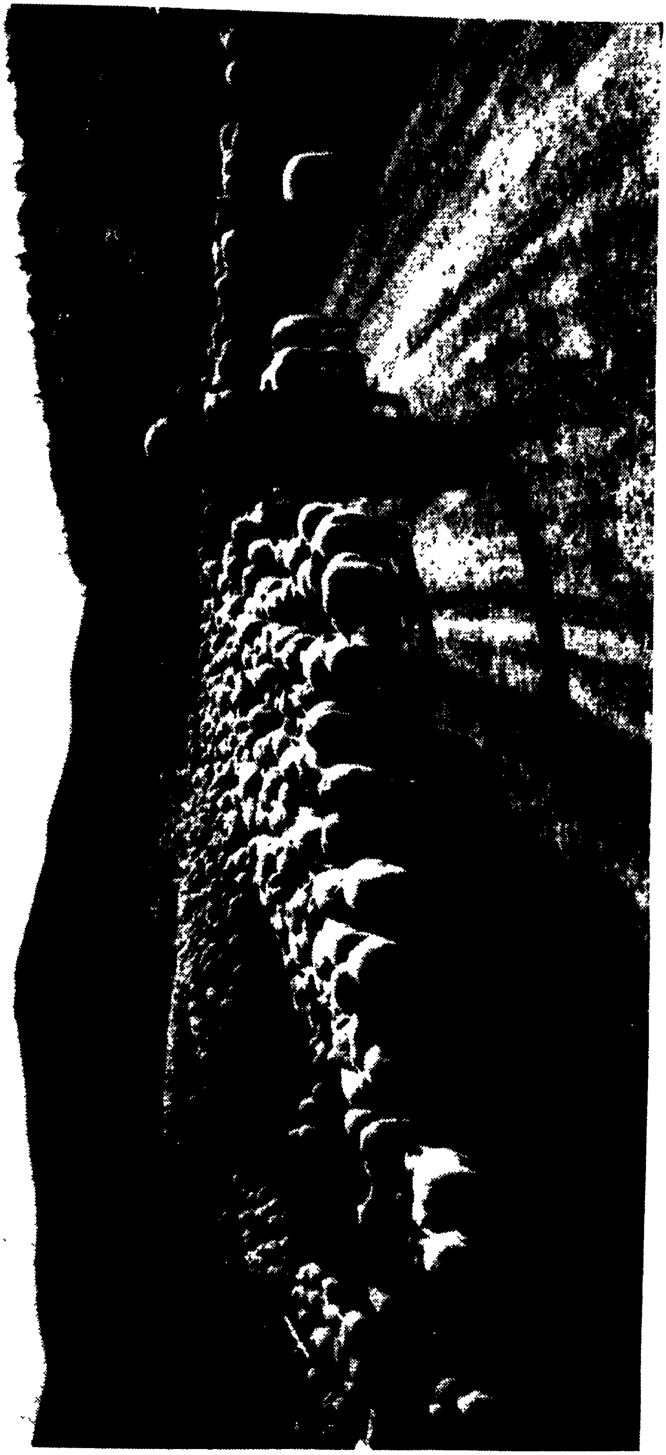

Figure 3.—A flock of range sheep in Idaho.

These rations are suitable for range ewes of about average size, weighing from 110 to 140 pounds. Ewes with twin lambs may need a little more grain and succulent feed (*192*). The feeds in the rations are normally grown in the irrigated valleys of the western range country.

POISONOUS PLANTS

Some of the most serious feeding problems encountered by range sheep producers result from poisonous plants that are eaten by sheep while grazing (*1093, pp. 263–264*). Plants that cause sickness and death among sheep occur in all parts of the United States. However, because of the greater number of sheep on the range and the method of handling them, the losses of economic importance are confined largely to the western range country. Where good forages are plentiful, sheep that are left to themselves or that graze in loose formation seldom eat enough of any poisonous plant to suffer from its effects; but under the system of close herding that prevails in many regions, where sheep eat practically all the vegetation as they move along, they are more liable to poisoning, and sometimes heavy losses occur.

The three groups of plants on the western ranges that are especially destructive to sheep are the species of death camas found in the higher parts of the Great Plains and west to the Pacific; the locoes, especially white loco, found on the Great Plains from Canada to Mexico; and the lupines, which are even more widely distributed than death camas. Lupine leaves rarely, if ever, injure sheep, but the pods and seeds, which are eaten during the summer and fall months, have caused heavy losses.

The laurels and leaves of wild cherries both in the East and in the West, the milk weeds and rayless goldenrod of New Mexico and Texas, the Colorado rubber plant of Colorado and New Mexico, and the coffee bean of Texas are some of the other plants that cause losses. The western sneezeweed is especially harmful in Utah and some parts of the Southwest.

No practical methods have been devised for eradicating most of these poisonous plants. However, a careful herder who is familiar with the plants and the places where they grow can do much to assist in preventing such losses.

LOOKING TOWARD THE FUTURE

Feeding experiments with sheep and lambs have been conducted extensively by experiment stations in some of the more important sheep-producing regions of the United States. Some of these experiments have included fundamental research on nutrition (*32*), but the majority of them have been conducted as rather practical feeding trials in which the lambs or sheep have been fed in groups of about 20 to 30 animals and occasionally as many as 100 or more. Many of these trials have resulted in information of definite practical value to sheepmen. They have often served as excellent guides for determining the feeds, the combinations of feeds, and the methods of feeding for efficient production of mutton and wool.

Many phases of the sheep production enterprise that involve feeding can still benefit greatly from feeding trials on numerous unsolved problems. With the increasing need for economy in feeding practices, however, producers of lambs and wool will need more definite information of a type that can be developed only by fundamental research—for example, on the specific roles of minerals, proteins, and vitamins in the nutrition of sheep (*169*).

It has been proved that the growth of wool can be controlled in large measure by feeding. Factors in the environment of a healthy sheep such as temperature and humidity have much less influence than nutrition on the production of strong, normal wool. The kind of feed provided for growing lambs is so important that even when choice roughages such as clover hay and corn silage have been given as the only feed to weaned lambs in the feed lot, they have failed to gain in weight, whereas the brothers of these lambs gained and developed normally when 1 to 1½ pounds of corn and about one-sixth of a pound of cottonseed meal per lamb per day were added to the roughage (*473, 631*). Adequate feed is one of the most necessary factors in profitable production of mutton and wool, both for quantity and for quality.

There are great differences in the efficiency with which individual sheep convert feed into meat and wool. The Bureau of Animal Industry has found a difference as great as 38 percent in rate of gain between the slowest and the fastest individuals fed similar rations in the same environment. In terms of total digestible nutrients per pound of gain, there was a difference of 36 percent between the least and the most efficient individuals. Large differences in nutritional efficiency have also been found between families of sheep. It follows that by applying the principles of both nutrition and genetics, breeders should be able to develop strains of sheep that could raise the level of efficiency in the economical use of feed. It is true that such an undertaking is complex and difficult, but it offers such an important reward that the effort seems justified.

Relatively little is known about the exact nutritive value of large numbers of forage plants that are grazed by sheep on pastures and ranges in the United States (*1006, 1007*). Experiment stations in the future should find definite research to determine these nutritive values one of the most promising ways by which nutrition specialists can serve the sheep industry. So large a part of the feed of sheep is in the form of grazing forage that definite nutritional indices of the important forage plants at various stages of growth should be vital and basic to the development of sound programs in sheep pasture and range improvement.

The pioneer phase of the sheep industry has passed. Free or even cheap grazing is becoming more and more scarce. The need for economy is so great that careless and wasteful methods will lead to failure. Sheep feeding and grazing must now be handled with the utmost care and along the lines of the most scientific thought if the enterprise is to prove profitable.

FEEDING PROBLEMS WITH GOATS

by Damon A. Spencer[1]

MOST of this article is concerned with the feeding of milk goats, though the essentials are briefly given for Angoras as well. Rations are suggested for milking does, young does, kids, and bucks, and for finishing goats that are to be sold for meat. A final section deals briefly with research needs in the nutrition of goats.

A LARGE PROPORTION of the goats in the United States are of Angora breeding. They are kept primarily for the production of mohair, and the majority of them are raised on fenced ranges of the Edwards Plateau in southwestern Texas (fig. 1), although they are fairly important in New Mexico, Arizona, California, Oregon, and Missouri, and a few are raised in several other States (*1232*).[2] California is the State most noted for the production of milk goats, the only other improved type (*1174*, *1175*). There are fewer milk goats than Angoras, but they are more generally distributed over the United States (fig. 2) (*765*). The leading breeds of milk goats in this country are the Toggenburg, Saanen, Nubian, and Alpine (*933*).

The feed requirements of goats are similar to those of sheep (*957*). Goats of all types are browsers by nature, fond of leaves, twigs, and weeds (*532*). While they also relish good grass, they will select browse, if given an opportunity, to a greater extent than will sheep (*1135*). When browse and other forage of range and pasture are not available, goats can make good use of legume hay; or they can subsist on straw, corn stover, timothy hay (if cut when in early bloom), corn silage, sorghum silage, and other nonnitrogenous roughages if these are supplemented with about one-fourth to one-half of a pound per head per day of protein-rich concentrates such as cottonseed or linseed cake or meal. Corn, oats, barley, and similar grains may be fed to goats along with roughage in about the same way that grains are fed to sheep. Good legume hay, however, is one of the best of the stored feeds for goats (*819*).

Milk contains a relatively large amount of protein, and mohair

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[2] Italic numbers in parentheses refer to Literature Cited, p. 1075.

Figure 1.—Angora goats grazing and browsing on the Edwards Plateau, Tex.

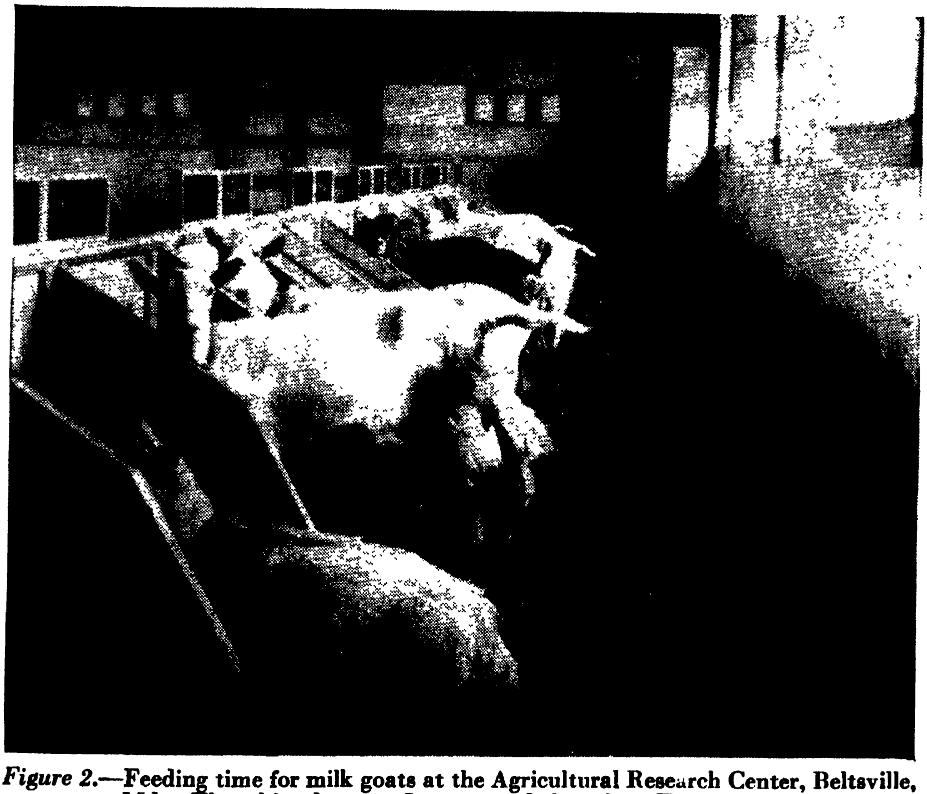

Figure 2.—Feeding time for milk goats at the Agricultural Research Center, Beltsville, Md. The white does are Saanens and the others Toggenburgs.

fibers, like wool fibers, are composed of protein. Goats therefore need feeds that contain a good supply of this nutrient (*819*).

Goats are as fond of salt as are sheep, and when they are accustomed to it, it should be kept where they can take as much as they desire. Calcium supplements may be needed where the forage is nonleguminous and grown on soils low in calcium. About a quarter of a pound of ground limestone or some other calcium supplement per head daily may be fed in the form of a mixture of 2 parts of calcium supplement to 1 part of common salt. If phosphorus appears to be lacking in the forage it may be supplied in bonemeal in a similar mixture with salt. Where there is trouble from goiter in newborn kids the does should be fed iodized salt at least during the last half of pregnancy, so that they will get about one-twentieth of a grain of potassium iodide per head daily (*819*). Larger doses may be injurious (*460*).

FEEDING ANGORA GOATS

Angora goats obtain most of their feed on the range in the form of browse, weeds, and grass. During the winter they subsist in large measure on evergreen brush (not including cedar or other coniferous vegetation) when such browse is available. When supplemental feed is necessary they can use to advantage hay, kale, rape, corn, milo maize, feterita, oats, and similar feeds. If the hay or other roughage is nonnitrogenous, they should be fed protein-rich meal or cottonseed or linseed cake. When they must depend entirely on stored feed, the daily allowance per head may need to be about 3 or 4 pounds of good-quality roughage and about one-fourth to one-half of a pound of concentrates. The bucks do well on the same kinds of feed as those on which the does thrive, but they may need slightly larger quantities in about the same proportion as their body weight exceeds that of the does. The kids in a herd of Angora goats are usually raised as suckling kids on their mothers' milk and on feeds available to their mothers (*1223*).

FEEDING MILK GOATS

The feeding requirements of milking does are similar to those of dairy cows (*141*). About six to eight goats can be fed on the quantity of feed required by one cow. When does are in milk they need all the roughage they will consume. Alfalfa, clover or mixed hay, and corn stover are satisfactory. The does also need succulent feed such as silage, mangel-wurzels, carrots, rutabagas, parsnips, or turnips. Corn, oats, wheat bran, barley, and linseed meal or cake are among the best concentrates for their ration. Other satisfactory concentrates, which may sometimes be more readily available, include cottonseed in the form of meal or cake, brewers' grains, corn bran, gluten feed, and beet pulp (*70*).

A very satisfactory ration for a doe in milk during the winter consists of the following daily allowance:

2 pounds of alfalfa or clover hay (good to choice);
1½ pounds of corn silage or roots;
1 or 2 pounds of grain mixture.

The grain mixture could consist of 100 pounds of corn, 100 pounds of oats, 50 pounds of wheat bran, and 25 pounds of linseed meal.

When on good pasture the doe may need a daily allowance of 1 to 1½ pounds of such a grain mixture. Does vary considerably in their appetites and there is an advantage in feeding them grain individually according to the quantities they will consume readily. Tests by the Bureau of Animal Industry show that, in producing a good milk flow, 1 pound of the grain mixture is the average daily grain requirement per quart of milk produced during the entire period of lactation (*933*). Under average conditions, a mature doe that is pastured as much as possible will require about 500 pounds of good to choice legume hay and 450 pounds of grain a year.

Young does should be kept in good growing condition (*266*). If they have plenty of browse and pasture it is unnecessary to feed them grain during the spring, summer, and fall, but they may need a little grain if the browse and pasture are short. In winter they need about 1 pound of grain, 1 to 1½ pounds of silage or roots, and all the hay or other roughage they will consume.

When the milk is to be sold or used by the family (*597*) the feeding of the kids that are to be raised for breeding and milking purposes requires special attention (*934*). Each kid should receive about 1½ to 2 pounds of milk a day along with good pasture or other roughage and a little grain. The grain mixture suggested for the older goats will be satisfactory, except that the corn should be cracked and the oats crushed, and the protein concentrate should be fed in the form of meal instead of cake. The quantity of roughage and concentrates at each feeding, when kids are fed twice a day, should be about as much as they will clean up before the next feeding. Tests by the Bureau of Animal Industry have shown that when the kids are about 10 weeks old the milk in the ration may be replaced in large measure by good alfalfa hay and mixed grain without sacrificing gain in body weight or development (*933*). This possibility offers an important advantage to the producer who needs to sell all the milk from the herd not required for raising the kids (*1071*). Whole cows' milk can be fed successfully to kids. Even skim milk can be used with a fair degree of success if the change from whole milk to skim milk is made very gradually and the kids are allowed 2 or 3 pounds of milk a day in three feedings until they are about 6 weeks old. Choice alfalfa hay and grain should be fed in addition to skim milk. During the first 6 weeks of the kids' life, milk should be fed warm at a temperature ranging from 90° to not more than 98° F. The kids can be weaned when they are 3 or 4 months old, although when they are raised as suckling kids it is customary not to wean them until they are about 5 months of age (*104*).

Bucks of the milk-goat breeds need some legume hay and corn stover during the winter, and it is a good practice to allow them some succulent feed such as silage, turnips, or other root crops, and sufficient grain to keep them in strong, thrifty condition. Bucks in the Department's herd of milk goats at Beltsville have wintered well on about 3 pounds of alfalfa or clover hay, 1 to 1½ pounds of corn silage, and 1½ pounds of grain per head daily, the grain mixture consisting of 100 pounds of corn, 100 pounds of oats, 50 pounds of wheat bran, and 25 pounds of linseed meal. During the breeding season the daily grain allowance is usually increased to 2 pounds. When bucks are on good pasture no grain is necessary.

FEEDING GOATS FOR MEAT PRODUCTION

Although goats have not been especially improved for meat production, the meat of healthy, normal goats is wholesome food. Many thousand goats are marketed for their meat annually, and the feeding of such animals has an important bearing on their market value. The normal goat carcass is not so well fleshed, is not susceptible of so high a finish, and does not represent so high a dressing percentage as the normal sheep carcass. Goat meat in the carcass form usually goes into the regular meat trade as mutton or lamb since there is only an occasional municipal restriction against such practice. The word "chevon" has been adopted to designate goat meat (*933*).

In grazing or feeding goats for their meat the same grazing forages or stored feeds should be provided for them as those given to Angora goats for the production of good strong mohair or to milk goats for the production of a good quantity of nutritious milk. However, in order to obtain the best finish, emphasis should be placed on such fattening feeds as corn, barley, or grain sorghums, along with good grazing forage or legume hay and succulent feeds. The daily allowance per head of stored feeds for fully grown goats should be approximately as follows:

2 pounds of good to choice alfalfa or clover hay;
1½ pounds of corn silage or roots;
1 or 2 pounds of grain.

The feed allowances will vary for goats of different ages, weights, and condition of flesh or fatness. The grain may be in the form of a mixture such as 2 parts of corn, 1 part of oats, and 1 part of wheat bran by weight.

POSSIBILITIES OF IMPROVING GOATS THROUGH NUTRITIONAL RESEARCH

Progress in feeding practices has been made by some producers of improved goats, but there is need for more definite information on the efficiency of various feeds and combinations of feeds, including the forage plants of pastures and range, from the standpoint of their influence on the quantity and quality of mohair and milk produced. As economy of production becomes increasingly important, the need for such information will be even more urgent than it is now. Fundamental research on the nutritional requirements of goats and their ability to utilize various feeds and combinations of feeds offers the primary means of increasing economy. Such research would include work on the precise role of minerals, protein, and vitamins in the nutrition of goats.

As in the case of sheep, there is much evidence of wide variations in the efficiency of individual goats to utilize feed. It is also apparent that such variations exist among different families and strains. Thus it should be possible to develop strains that are highly efficient in converting available feeds into mohair or milk of superior quality and quantity. Once such strains were developed, they could be used in suitable breeding practices to raise the average efficiency of these animals (*245*).

In such an effort the research workers in nutrition and genetics would have to cooperate with each other, and they would have to have the cooperation of the producers of mohair and milk. The pioneer period of goat production is passing, just as it is with sheep, and this inevitably means a need for greater efficiency based on theoretical research and practical experiment.

NUTRITION OF HORSES AND MULES

by Earl B. Krantz and S. R. Speelman[1]

THE first part of this article deals with the nutritional requirements of horses insofar as these have been determined; actually, there has not been very much experimental work in this field. The second part discusses practical feeding under different conditions, including suggested rations and the use of concentrates, roughage, and mineral supplements.

THE PRINCIPLES of the nutrition of horses and mules[2] fundamentally are not unlike those of other domestic livestock. Thus, for body building and maintenance, for growth, and for production, the horse and mule have need for protein, carbohydrates, fats, minerals, and vitamins, much as these essentials are required for similar vital processes by cattle, sheep, swine, and poultry. The relative importance of the various nutrients and the quantities required by horses and mules are, however, not the same as for the other farm animals.

Nor do the requirements of horses and mules necessarily remain the same from day to day or from period to period. The stage of life, the kind and degree of activity, climatic conditions, the kind, quality, and amount of feed, the system of management, the health and individuality of the animal, and perhaps other equally important factors are all continually exerting a powerful influence in the determination of nutritive needs. How well the individual feeder or experimenter understands, anticipates, interprets, and meets these requirements usually determines the success or failure of the ration and of horse or mule keeping.

The present discussion of the nutritive requirements of horses and mules considers the subject briefly from the standpoints of adequacy of rations, feed economies, and feeding practices.

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[1] Earl B. Krantz was formerly Animal Husbandman, and S. R. Speelman is Associate Animal Husbandman, Animal Husbandry Division, Bureau of Animal Industry.

[2] Although most of the research and investigational work in the field of nutrition has not considered mules, the results obtained from some tests and from practical experience indicate that their requirements for feed are essentially the same as those of horses. The nutritive needs of horses and mules are accordingly treated as one in this article.

NUTRITIVE REQUIREMENTS

PROTEIN

Horses and mules of all ages and kinds need adequate amounts of protein of suitable quality.

Protein is required for building new tissues and for replacing protein lost from the body in the general wear and tear of normal body processes. Actual protein requirements for these processes can be described in terms either of nitrogen used by the body or of amounts of a theoretically complete or perfect protein which contains all the amino acids needed in exactly the proportions required by the body. In this respect no one food protein is perfect, and proteins from various sources vary widely in their biological value.

Knowledge concerning the actual protein requirements of horses is rather scant, but feeding standards have been established as a result of experiments as well as of practical experience that suggest amounts of crude digestible protein estimated to cover the protein requirements with a suitable margin of safety. These standards take into account the variability in nutritional value of different food proteins, as well as some variations in quantitative requirements.

During the stage of growth and development of the young horse or mule, particularly the first year, the relative need for protein is greater than at any other time of life. The amounts needed daily for 100 pounds of live weight are usually greatest at the earliest ages and smallest weights, declining gradually as the animal ages and increases in size. The needs of the growing animal for protein for building new tissues are responsible for most of the excess in its protein requirements over those of mature animals. The relative demands for protein of colts and of mature horses of various classes are shown in recommendations for the daily intake of this nutrient in some feeding standards, such as those of Morrison (*819, pp. 1006–1007*),[3] which are given in table 1.[4] Morrison suggests that the daily protein needs of the 500-pound draft colt are amply covered by 0.18 to 0.20 pound per 100 pounds of live weight, while for the 1,000-pound mature idle work horse the quantity specified is 0.06 to 0.08 pound.

In ordinary feeding practice it is assumed that the quantitative needs for protein among young growing animals are the same for both sexes. A report by Mitchell (*796*), however, states that "females put on gains containing a smaller percentage of calories in protein than males." This indicates that the protein requirements of the growing female may be somewhat less than those of the male, but the difference is probably not of importance in practical feeding. Estimates for the combined amounts of protein required daily for growth and maintenance in draft colts weighing 400 to 1,200 pounds, as made by Morrison (*819, p. 1007*), are given in table 1.

The optimum and minimum quantitative needs of colts for protein during the growth period are unknown at the present time, except for information developed from practical experience. The need for experimental research on this subject is evident.

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[3] Italic numbers in parentheses refer to Literature Cited, p. 1075.

[4] The Morrison standards have been selected for purposes of discussion because their recommendations cover the nutrition of horses of various kinds and because they are applicable to many of the methods that have been found to be practical and economical under average and normal conditions.

TABLE 1.—*Morrison's feeding standards for horses*

Type and weight (in pounds) of animal	Requirements per head daily				
	Dry matter	Digestible protein	Total digestible nutrients	Nutritive ratio,[1] 1 to —	Net energy
Horses, idle:	*Pounds*	*Pounds*	*Pounds*		*Therms* [2]
1,000	13.0–18.0	0.6–0.8	7.0–9.0	10.0–12.0	5.6–7.2
1,200	14.8–20.6	.7– .9	8.0–10.3	10.0–12.0	6.4–8.2
1,400	16.6–23.0	.8–1.0	8.9–11.5	10.0–12.0	7.2–9.2
1,600	18.3–25.4	.8–1.1	9.9–12.7	10.0–12.0	7.9–10.1
1,800	20.0–27.6	.9–1.2	10.8–13.8	10.0–12.0	8.6–11.1
Horses at light work:					
1,000	15.0–20.0	.8–1.0	9.0–11.0	9.0–11.0	7.5–9.1
1,200	17.4–23.1	.9–1.2	10.4–12.7	9.0–11.0	8.7–10.5
1,400	19.6–26.2	1.0–1.3	11.8–14.4	9.0–11.0	9.8–11.9
1,600	21.9–29.2	1.2–1.5	13.1–16.0	9.0–11.0	10.9–13.3
1,800	24.0–32.0	1.3–1.6	14.4–17.6	9.0–11.0	12.0–14.6
Horses at medium work:					
1,000	16.0–21.0	1.0–1.2	11.0–13.0	9.0–11.0	9.4–11.1
1,200	18.8–24.6	1.2–1.4	12.9–15.2	9.0–11.0	11.0–13.0
1,400	21.5–28.2	1.3–1.6	14.8–17.4	9.0–11.0	12.6–14.9
1,600	24.1–31.6	1.5–1.8	16.6–19.6	9.0–11.0	14.2–16.7
1,800	26.7–35.0	1.7–2.0	18.3–21.7	9.0–11.0	15.7–18.5
Horses at hard work:					
1,000	18.0–22.0	1.2–1.4	13.0–16.0	9.0–11.0	11.3–13.9
1,200	21.3–26.1	1.4–1.7	15.4–19.0	9.0–11.0	13.4–16.5
1,400	24.7–30.2	1.6–1.9	17.8–21.9	9.0–11.0	15.5–19.1
1,600	28.0–34.2	1.9–2.2	20.2–24.8	9.0–11.0	17.5–21.6
1,800	31.2–38.1	2.1–2.4	22.5–27.7	9.0–11.0	19.6–24.1
Brood mares nursing foals, not at work:					
1,000	15.0–22.0	1.2–1.5	9.0–12.0	6.5–7.5	7.6–10.0
1,200	17.4–25.5	1.4–1.7	10.4–13.9	6.5–7.5	8.8–11.6
1,400	19.6–28.8	1.6–2.0	11.8–15.7	6.5–7.5	10.0–13.1
1,600	21.9–32.1	1.7–2.2	13.1–17.5	6.5–7.5	11.1–14.6
1,800	24.0–35.2	1.9–2.4	14.4–19.2	6.5–7.5	12.2–16.0
Growing draft colts, after weaning:					
400	9.2–11.3	.8– .9	5.6–7.2	6.5–7.0	4.9–6.3
500	10.9–13.3	.9–1.0	6.6–8.4	6.6–7.1	5.7–7.3
600	12.4–15.2	1.0–1.2	7.6–9.6	6.7–7.2	6.5–8.3
700	13.9–17.0	1.1–1.3	8.5–10.8	6.8–7.3	7.3–9.3
800	15.3–18.7	1.2–1.4	9.4–11.9	6.9–7.4	8.0–10.1
900	16.7–20.4	1.3–1.5	10.2–13.0	7.0–8.0	8.7–11.0
1,000	18.0–22.0	1.4–1.6	11.0–14.0	7.0–8.0	9.2–11.8
1,100	19.3–23.6	1.5–1.6	11.8–15.0	7.2–8.2	9.9–12.6
1,200	20.6–25.1	1.5–1.7	12.6–16.0	7.5–8.5	10.6–13.4

[1] The ratio, or proportion, between the digestible protein and the digestible nonnitrogenous nutrients (including fat multiplied by 2.25).

[2] A unit employed in measuring heat and energy, equal to 1,000 calories.

Next to that of the young growing colt, the relative need for protein is greatest in the brood mare, whether pregnant, or nursing young, or both (fig. 1.) This is a result of the various physiological processes involved in gestation and lactation, which increase the protein demand. In the Morrison standards, the protein requirements (100-pound body-weight basis) for the 1,000-pound idle brood mare with suckling foal are set at 0.12 to 0.15 pound daily. If her maintenance demands are assumed to be approximately the same as those for work stock of the same weight, which is logical, the conclusion may be drawn that as much protein is required daily to produce milk for the foal as is needed for the upkeep and repair of her body. Moreover, this standard is applicable to mares of greater weights. The milk yields of mares nursing foals are variable, Morrison (*819, p. 467*) reporting them as between 26 and 77 pounds daily as determined by tests on draft mares in Germany. Since about 2 percent of the total volume (or about 20 percent of the total solids) of the milk is protein, the amount of protein in the daily milk yield of a mare would be between ½ and 1½ pounds.

Inasmuch as there is no conclusive evidence that ordinary work increases the protein requirements of healthy horses and mules, the theoretical needs of such animals for this nutrient should be the same whether idle or at labor. However, in practice, the amount of protein fed is usually increased with the amount and severity of work done, since it is difficult, using the commoner feeds, to increase total energy (digestible nutrients) without increasing the protein. The ingestion of somewhat more than the required amounts of protein will ordinarily do no harm, since protein can be readily utilized by the body to supply energy, though this may result in increased costs. The Morrison protein requirements for maintenance for idle work horses and mules have already been mentioned. The intake is practically doubled when the animals are at hard work (table 1).

None of the existing feeding standards contain specific suggestions for the intake of protein by stallions, whether idle, working, or in breeding service, nor is there available any exact experimental evidence on this subject. From practical experience, however, it appears that, unless he is worked regularly, the stallion's need for protein ordinarily should not vary greatly from that of idle work horses, mules, and open mares.

In addition to the Morrison feeding standards for horses there are others that cover this subject either directly or indirectly. One of these, which proposes standards for maintenance, was presented by Brody, Procter, and Ashworth in 1934 (*157*). In general, the protein

Figure 1.—**Both the mare and the young growing colt require adequate supplies of all the essential nutrients.**

allowances recommended by these workers are somewhat lower than those of Morrison, particularly in the case of young, lightweight animals.

In the young growing colt, the result of inadequate protein intake is usually evidenced by slow or stunted growth and improper development. With breeding stock, there may be impairment of the reproductive functions. Mature, idle stock ordinarily are not seriously affected if the lack of protein is not too great and does not extend over a long period. Work animals, however, may lack spirit and efficiency.

ENERGY

Consideration of the energy requirements of horses and mules[5] is divided into two parts: (1) The need for and utilization of feed nutrients for body maintenance, and (2) the quantitative expenditure of nutritive material for reproduction, lactation, and the accomplishment of useful work. The first is necessarily of most importance, because it involves all functions essential to the animal's existence.

The maintenance requirement is the amount of food or its constituents required to cover the needs of an animal in good health without gain or loss of weight. In the determination of energy requirements for maintenance, several factors may influence the quantitative demand for and the intake of food material—the age, size, and individuality of the animal; the kind, quantity, quality, and proportions of feeds used; and climatic and management conditions. The probable effects of some of these on maintenance requirements can be rather readily calculated or predicted, while others may only be estimated.

Inasmuch as size and age of the animal are the major factors affecting energy requirements for maintenance, their influence on total food intake is of primary importance. Formerly it was believed that the quantitative need for energy was directly proportional to the body weight of the animal. Present knowledge, however, indicates that energy requirements for maintenance are roughly proportional to surface area, or to the 0.65 to 0.75 power of the body weight of mature animals. The energy required for maintenance per unit of surface area in young animals is somewhat greater.

The effect of individual temperament on maintenance requirements is not readily predictable. There is a wide variability in temperament among horses and mules of different ages and kinds, and incidentally this factor is probably the one most responsible for the "good and bad doers" with which every horseman is more or less familiar.

Improper balance of nutrients in the maintenance ration, caused by excessive amounts of feeds with wide nutritive ratios, may result in depression of digestibility, poor feed utilization, stunted or improper growth, and impairment of health, if continued for a very extended period. Some research work on this subject has been reported by Dunbar (*286*), who conducted maintenance tests with horses using oat straw (nutritive ratio 1:48) as the sole feed. The animals tested showed a marked decline in ability to digest all types of nutrients except fat, a constantly increasing intake of total feed, decreasing vitality, and permanent damage to general health and efficiency.

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[5] The methods by which energy requirements of horses have been measured and determined are various and somewhat complicated. They have involved many elaborate tests for measuring the intake and expenditure of energy, digestibility of feeds, and the accomplishment of work.

Climatic conditions and the method of managing horses and mules affect their energy-maintenance needs. Very cold weather increases considerably the amount of energy required, as does also any mismanagement that keeps the horse or mule in a restless, excitable condition for any considerable length of time.

It has been indicated that the young, growing horse and mule have proportionately greater need of energy for maintenance per unit of body weight than the mature, idle animal owing to differences in body-surface area. The effects of rapid growth and the general acceleration of all vital processes due to a higher rate of metabolism, as well as the greater degree of body activity in the young, are also important considerations. For these reasons, the energy needs of a young horse or mule at weaning age (approximately 500 pounds body weight) may be relatively twice as great as those of the 1,000-pound, mature, idle animal and about the same as those for such a horse or mule when at hard work. Energy requirements for maintenance in young horses and mules are highest during the early stages of life and decline gradually as they approach maturity. When immature horses or mules are worked, their energy requirements will be increased somewhat, the amount being determined by the labor done.

The energy requirements of idle brood mares nursing foals are somewhat greater than those of idle geldings, dry mares, or mules of the same size. The need of the brood mare for additional nutrients is due principally to physiological demands in the production of milk for her young. It may also, however, be related to improper feeding during the gestation period, which may have caused body losses that must be repaired. The need for energy of the idle brood mare with foal is variable, depending on the milk yield. Normally, the extra feed required for the production of milk will approximate that required for light work by the open mare, gelding, or mule of the same size. Pregnant brood mares with nursing young have higher energy requirements than nonpregnant mares with suckling foals, particularly during the first few months of gestation.

Energy requirements of working horses and mules are determined almost entirely by the individuality and size of the animals and the kind, amount, and severity of the labor performed. Because of many factors difficult to evaluate, it is only possible to approximate what constitutes light, medium, and hard work under various conditions. On the farm, the operations of disking and breaking ground when done on a full-day basis are classed as severe work. Cultivation and haying jobs would generally come under the heading of medium labor. So far as feeding is concerned, part-time heavy work might be equivalent to medium labor. Again, from the feeding standpoint, light work could consist of any of these operations if done during short periods, or it might be easy hauling, etc. Ordinarily the feeder is the best judge of the kind of work done and the amount of energy required by the animals to do the job, the aim being to maintain body weight at a fairly uniform level thoughout the work period. The feed requirements of work stock at light jobs often are not much greater than those for idle animals. With severe work, however, the demands are greatly increased and are usually about twice those while idle.

Unless the stallion is worked, his energy requirements are about the same as those for idle work stock and animals at light work. The exact requirements, however, are determined by the amount of breeding work done, restlessness, travel, and the condition in which the stallion is kept.

Inasmuch as the major requirement for fattening farm animals of any kind is an abundant supply of total digestible nutrients (energy), the rations fôr increasing body weight in thin horses and mules must be relatively high in energy-producing materials, particularly carbohydrates. The total amount of energy needed by horses and mules for fattening is variable, depending on the age, individuality, and condition of the animals, the feeds used, and the rate of gain desired, but it approximates that of stock at hard work.

Lack of adequate amounts of energy-producing feeds in the rations of horses or mules may result in a number of consequences. When the energy deficiency is great in the feed of young animals, the result is usually slow and stunted growth, with consequent underdevelopment. Work animals that do not receive adequate amounts of energy will lose weight, get out of condition, and be unable to do their jobs without excessive fatigue. When the energy requirements of breeding stock and idle animals are not satisfied the effect is usually a loss in body weight.

Consideration of the many factors that may influence the energy requirements of horses and mules indicates that no hard and fast rules can be laid down that will adequately cover quantitative intake in all instances. Approximations of such requirements, however, which should be useful as guides, are presented in the Morrison feeding standards in table 1.

MINERALS

Chemical analysis of the body of a farm animal such as the horse reveals the presence of varying quantities of a rather large number of elements. Aside from hydrogen, oxygen, nitrogen, and carbon, the principal elements found are calcium and phosphorus. Other elements, present in either small or appreciable quantities, which in the light of present-day knowledge are believed to be essential to balanced, complete, and satisfactory nutrition, are sodium, chlorine, iodine, iron, potassium, sulfur, copper, magnesium, zinc, cobalt, and manganese. That the total of these elements in the horse is of considerable significance is indicated in the body analyses of three Percheron horses made by Mitchell and Hamilton (*610*), who found that the ash (mineral) content was 4.66 percent of the empty carcass weight.

The various mineral elements required by the animal body have both building and regulatory functions. The quantitative needs of horses and mules for these minerals and the best minerals for supplying the needs are matters of obvious importance in the practical nutrition of the horse and mule. Yet with the exception of data on water requirements, a few reports on salt (sodium chloride) consumption, and fragmentary research findings relative to calcium, phosphorus, and iodine, experimentation to date has given the horse and mule feeder no answers to many phases of this subject and few clues to assist him to work out the correct solution.

There appears to be little likelihood that these animals will suffer from deficiencies of iron, potassium, sulfur, copper, magnesium, zinc, manganese, or other minerals when fed normally, and no special attention need be given to the inclusion of these minerals in the ration.

Calcium and Phosphorus

To be of economic importance, a horse or mule must have a sound, fully developed body. Such development is possible only when the skeletal framework is adequate, and this may be assured by the judicious use of rations containing rather liberal amounts of calcium and phosphorus, the bone-building minerals.

Calcium and phosphorus together constitute approximately 75 percent of the total supply of body minerals and about 90 percent of the mineral matter in the bony skeleton. The need for calcium and phosphorus in the horse and mule ration is undoubtedly most pronounced during the growing stage, particularly during the first year of life. It has long been known by practical horsemen that the colt should have acquired about one-half its total growth (body-weight basis) when it is 1 year old. This is supported by experimental evidence, particularly the recent work of Hudson at the Michigan State Agricultural College (*549*), and of Trowbridge and Chittenden at the University of Missouri (*1149*). In his investigations with young draft horses of Belgian and Percheron breeding, Hudson determined that the greatest development of the skeleton takes place before a colt is 1½ years of age, while Trowbridge and Chittenden found that during the first year of life their experimental animals (Percheron foals) had acquired 50 to 60 percent of the total increase in body weight; 65 to 70 percent of the total increase in depth and circumference of chest, width at hip points, and size of fetlocks and coronets; and as much as 90 percent of the total increase in some important body dimensions. If 99 percent of the calcium supply of the animal body and approximately 80 percent of its phosphorus content are in the bones (*803, p. 10*), such skeletal and body increases can logically mean but one thing—the ingestion and utilization of relatively large quantities of these two elements by the growing animal. The quantitative need for calcium and phosphorus decreases gradually as animals approach maturity. Unfortunately, there are apparently no experimental data on the requirements for calcium and phosphorus by young horses and mules that either verify or refute the practical observations and conclusions drawn. Mitchell and McClure (*803, p. 87*) believe that the intake of these minerals should be equivalent to 0.2 percent of the dry ration.

Reproductive functions increase the mineral requirements of the breeding mare, and her demands for calcium and phosphorus are relatively high both during pregnancy, especially the latter part, and while she is nursing her foal. As in the case of young, growing horses, no research data are available on this subject to indicate either quantitative intake or utilization of mineral matter by brood mares. If, as frequently happens, the mare with a suckling foal is rebred and becomes pregnant, the demands for calcium and phosphorus will be increased, particularly during the first half of the gestation period, for she is then called upon to supply the materials to develop the unborn fetus and at the same time produce mineral-rich milk[6] for her nursing young.

The mineral demands for the maintenance of mature stallions are unknown, but insofar as the need for calcium and phosphorus are concerned, it is possible they may be about the same as those for work geldings and dry mares in most instances.

Despite the lack of clear experimental evidence, it seems probable that the needs for calcium and phosphorus by mature work horses (geldings and dry mares) and mules are not nearly so great as those for young stock and brood mares, because ordinary muscular work, if not carried to the point of fatigue, is not known to have any marked effect on mineral requirements where there is an adequate supply of energy material in the diet (*803*). Thus, it is thought that few deficiencies of these minerals will be encountered under ordinary normal farm feeding practices, particularly if some good legume hay and adequate pasture are supplied.

It has been stated that the literature on mineral nutrition in horses does not reveal pertinent data on the daily ingestion of calcium and phosphorus by animals of different ages and kinds. This is true in general, but note should be made of the deductions that Mitchell and McClure drew from analyses of horses carcasses (*803, p. 68*), using growth data obtained from University of Missouri tests and Morrison's feeding standards. From this calculation, they roughly estimate that between the weights of 400 and 1,600 pounds a Percheron horse needs a daily allowance of 13.5 grams of calcium (9.0 for growth and 4.5 for maintenance) and 13.6 grams of phosphorus (4.7 for growth and 8.9 for maintenance).

From the evidence on mineral malnutrition now available it is apparent that horses and mules of all ages may be adversely affected in various ways when the calcium and phosphorus intake is inadequate, when these elements are ingested in disproportionate amounts, and when there is a faulty utilization of either mineral by the body. In very young animals, calcium and phosphorus malnutrition is most evident in the arrest or distortion of normal bone growth. Unless this is corrected in time, it quite often culminates in the disease known as rickets. With older horses and mules calcium and phosphorus malnutrition may lead to a number of consequences. If the deficiency is one of calcium alone, both the skeletal tissues and the reproductive functions of horses may be affected. Phosphorus deficiencies do not seem to occur as often in horses and mules as in other species of livestock, although in certain localities they frequently cause underdevelopment in horse stock (*18*).

Lack of calcium in the horse ration, when intensified by the presence of high-phosphorus protein concentrates, is believed to produce the condition commonly known as osteomalacia or osteodystrophia fibrosa (*803*), which is prevalent in various parts of the world and affects not only horses but asses and their hybrids, with the young of the species most susceptible. This disease is usually characterized by an initial period of stiffness and lameness, followed by swelling of the jaws and the nasal and frontal bones of the head, bone fractures, detachment of ligaments, anemia, emaciation, and death. Because of the great increase in head size that may occur during osteodystrophia fibrosa, it has become popularly known as bighead in some countries. It is said to develop when the calcium-phosphorus ratio of the ration is 0.55 to 1 or less and to be arrested by the addition of calcium supplements until the ratio becomes 1.6 or more of calcium to 1 of phosphorus (*803, p. 17*).

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[6] Over 50 percent of the mineral matter in milk is calcium and phosphorus.

No data definitely indicate the optimum proportions of calcium and phosphorus for horses and mules. It is thought, however, that the ratio of calcium to phosphorus should be somewhere between 2 to 1 and 1 to 1 under ordinary conditions.

Salt

Horses and mules of all ages and kinds need sodium chloride—common salt—regularly in their diet. Aside from the function which sodium chloride has in the maintenance of body-cell osmotic pressure and the role of hydrochloric acid in digestion, the part that these elements, sodium and chlorine, play in the mineral metabolism and other life processes of such animals is not well understood. Nor is there much experimental evidence which pertains to this matter in any way. Insofar as the quantitative intake of salt by horses and mules is concerned, existing data and practical observations indicate that the principal determining factors are individuality of the animal (irrespective of age) and the degree of body activity. That the matter of individuality is a particularly pertinent factor is indicated by tests conducted with draft horses at Michigan State Agricultural College (*548*), which showed a range in daily salt consumption of 0.27 to 3.26 ounces and an average daily intake of 1.82 ounces per head for animals kept under like conditions of feed and work. Such consumption, however, does not necessarily indicate the needs of the individual animals for sodium and chlorine, because it is entirely possible that more salt was consumed by some of the horses than was actually required. The influence of hard work on salt consumption and possibly on salt requirements is apparent from practical experience and observation. When at heavy labor, particularly during warm weather, the horse and mule sweat profusely and this carries considerable salt from the body in the form of visible excreta. Unless this salt is replaced, the animals will soon exhibit signs of excessive fatigue, a fact that points to the possibility of some direct correlation between salt requirements and the expenditure of energy.

Iodine

According to Mitchell and McClure (*803, p. 71*):

> The only known function of iodine in the nutrition of the higher animals is to serve as an indispensable constituent of thyroxine, an amino acid found in thyroglobulin, the characteristic protein of the thyroid gland.

Except in certain areas and under abnormal feeding conditions, the problem of adequate iodine intake and utilization is of minor significance with horses and mules. There is a region, however—the so-called goiter belt—where iodine deficiencies in feeds may be a major problem, particularly with brood mares and colts. In this section, experimental evidence indicates that the use of iodine supplements is generally beneficial. For this purpose Rodenwold and Simms (*978*), of the Oregon State Agricultural College, recommend 15 grains of potassium iodide weekly for pregnant mares during the last 5 or 6 months of the gestation period in order to produce normal, strong foals, free of congenital goiter. Iodine is also given to horses and mules by some feeders in the form of iodized salt, which is apparently an effective method of administration when properly handled. The amount of potassium iodide in such salt usually approximates 0.02 percent (equivalent to 1 ounce in 300 pounds), but some may be lost by oxidation when the salt is exposed to air. Consideration should be given this fact when calculating the iodine supply needed.

VITAMINS

The role played by vitamins in the nutrition of the horse and mule has not been explored extensively. However, there is reason to suppose that the vitamin requirements of horses and mules are similar to those of other animals, and it seems probable that ordinarily there will be few serious deficiencies of any of the vitamins except A and D.

The importance of vitamin A or its precursor carotene is indicated by its relation to two important attributes of a horse—eyesight and hoofs. Night blindness resulting from a deficiency of vitamin A has been demonstrated experimentally in horses; and the injurious effect of lack of vitamin A on the hoofs has been indicated by experiments with horses in the army of Finland (*636*). The uneven and poor development of the hoofs of these horses, which had been fed chiefly on old hay, was cured by supplementary feeding of pasture grasses, grass silage, or cod-liver oil.

FEEDS AND ECONOMICAL FEEDING PRACTICES

Size, age, condition, individuality, working conditions, and production needs of horses and mules are the principal factors affecting feed requirements.

As indicated, little definite knowledge exists on the nutritive values of feeds for horses and mules or the protein, energy, mineral, and vitamin requirements of these animals. Although a few digestion trials have been made with horses, the number of animals used in such tests has been limited, and most of the theoretical feed requirements for horses and mules have been calculated from experiments with ruminants. Comparative feeding tests with horses and mules are also limited in number. In addition, the number of animals used was often so small or the differences in body weight were so slight that the experimental results were reported as of doubtful statistical value. Simms (*1060*) points out extreme variations of 136 pounds per individual within the same lot of experimental animals over a period of 21 months, and he doubts—

> if average differences in gains or losses in weight amounting to much less than 100 pounds in 12 months are of real significance in feeding tests where teams or small groups of horses are compared.

Individuality among horses may be a big factor in much of the irregularity found in the experimental results obtained with small numbers of animals. Kind and amount of work done also may have varied the results obtained from similar rations in such tests.

In determining the comparative merits of the more common feeds for horses and mules and the most efficient feeding practices for their production and use, results of practical feeding experience may be added to the limited knowledge of theoretical requirements and the somewhat doubtful results of comparative tests.

Oats, corn, and barley, all farm-grown concentrates, are the grains most generally used for horses and mules, and alfalfa, clover, soybean, timothy, prairie, Johnson grass, and grain hays are the most common forages fed in different sections of the United States. Wheat bran and linseed meal are the most favored supplements to the grains, although cottonseed meal and some other supplemental concentrates are fed to horses and mules in considerable quantities in the South and other sections where such feeds are available at low prices.

Of the common feeds, those grown locally are ordinarily the cheapest to use and as a general rule work into the ration most satisfactorily. For this reason it is well to plan the ration largely on the basis of the feeds most readily available, and sufficient variety may usually be obtained by a judicious combination of home-grown products.

CONCENTRATES

Oats

Oats rank as one of the best grains for horses. While they are not so high in total digestible nutrients as either corn or barley, a suitable protein content and the bulky nature of this feed make it particularly valuable for many horses. Many horsemen consider that oats have no equal as a horse feed. This may be erroneous, however, as both experimental and practical feeding experience have shown that some other feeds, when properly combined, may be either equal or superior to oats. Oats are especially suitable for work horses and mules during hot weather, for horses worked irregularly, and for the steady feeding of light-type horses.

Corn

Corn is the most commonly used concentrate for horses in the Corn Belt. It has a higher energy value than oats, it is ordinarily cheaper per hundred pounds, and it is particularly valuable when used in combination with oats. Corn does not, however, have as great a calcium or phosphorus content as oats. When fed with alfalfa or other legumes, corn usually produces excellent results. The alfalfa adds the necessary protein and supplies minerals and vitamins, all of which are low in corn. If corn is fed as the only grain with grass hay, some protein supplement should be used to balance the ration. Corn is most commonly fed to farm horses on the ear or shelled. Corn meal, if used at all, should be combined with oats, wheat bran, or some other light, bulky feed.

Most experiments have shown very little difference between the feeding values of corn and of oats for work stock. Feeding tests in

Ohio, New York, Illinois, Kansas, and Missouri (*191*, *478*, *707*, *866*, *1147*), for example, proved that corn in the ration of the farm work horse or mule was entirely satisfactory and lowered the cost of the ration somewhat.

Barley

Barley is used as the principal grain for horses in many parts of the West. Because of its physical character it should be either rolled, crushed, or coarsely ground to prevent digestive disturbances. While barley has a little more digestible protein and more total digestible nutrients than oats, it is neither so widely grown or used nor so generally popular a feed among horsemen.

Other Grains

Wheat, rye, rice, and some leguminous seeds (*92*), are used as feed for horses under limited conditions. Wheat is satisfactory when crushed or rolled, and may be fed in moderate quantities in conjunction with some bulky concentrate. Rye also must be crushed or rolled and should be limited to not more than one-third of the grain ration. Rice must be ground, rolled, or soaked, and should be used in limited amounts combined with such feeds as corn, blackstrap molasses, and protein supplements. All leguiminous seeds should be ground, and even then they may cause digestive disturbances if they constitute more than one-third of the concentrate allowance.

Wheat Bran

Wheat bran is a favorite feed among horsemen because it is high in protein and phosphorus, is palatable and bulky, and has a laxative effect. Where corn is the principal grain and the cheapest feed available, the use of wheat bran (10 to 20 percent) is particularly desirable. Even with alfalfa hay, the use of a small amount of wheat bran improves any grain ration, because alfalfa, while high in calcium, is low in phosphorus. Wet bran is more laxative than dry bran and is often used once or twice weekly as a mash for horses doing irregular work.

Linseed Meal

Old-process linseed meal is used both as a protein supplement and as a conditioner. Its laxative and conditioning properties make it an ideal commercial supplement in amounts from ½ to 1 pound per horse daily. Larger allowances may prove too laxative. In Kansas (*707*), corn, wheat bran, and linseed meal, in a 6:3:1 ratio, with prairie hay, proved to be well adapted for horses at hard work. The advisability of using linseed meal in limited amounts ordinarily depends upon the type of hay fed, comparative feed prices, and whether or not its utilization makes possible the major use of feed of lower cost.

Cottonseed Meal

Cottonseed meal is a nonlaxative protein supplement that may be fed to horses and mules in limited quantities, if the animals are put gradually on bright, choice-quality meal. While most authorities have recommended that not more than 1 pound daily per 1,000 pounds live weight be fed, experiments in Texas (*1226*) indicate that 1 to 2 pounds of 43-percent-protein cottonseed meal usually may be fed to horses and mules. It is best to mix cottonseed meal with oats, wheat bran, or some other bulky feed. In the South, this feed is a valuable supplement to corn-and-cob meal, particularly if a legume hay is not available.

HAYS AND OTHER ROUGHAGE

It is very important to consider both the quality and the percentage of roughage in planning an efficient and economical ration for horses and mules. Because the stomach of these animals is comparatively small and the energy expended in work is large, the need for a balanced ration of suitable quality and physical character is most important, especially when the animals are at hard work. At this time the amount of roughage should be relatively small and its quality high. More roughage, of lower quality, may be used under light work conditions and during idle periods. In making the choice of roughage it is well to remember that legume hay is particularly valuable for its mineral and vitamin content and may be used to correct deficiencies of these nutrients in some of the common farm grains.

Timothy Hay

Bright, clean timothy hay has long been considered one of the best dry roughages for horses. Much of this popularity is due to the excellent quality of hay that may be made when timothy is properly cut and cured and to its wide distribution and availability. As timothy hay is lower in protein and total digestible nutrients than either mixed or legume hays, it is generally not so valuable for horses as legume hay of equal quality fed in limited amounts or mixed hay of equal quality and quantity.

Johnson Grass Hay

Johnson grass is grown extensively in certain sections of the South. In these sections, this grass is used to advantage as forage for horses. Johnson grass hay compares favorably with timothy in protein and total digestible nutrients and is higher in both calcium and phosphorus.

Alfalfa Hay

Alfalfa hay, because of its high content of protein, energy, minerals, and vitamins and its palatability, is much more valuable than timothy or other grass hays for horses. As pointed out in the discussion on corn, alfalfa is especially suited for use with a grain ration that is low in protein. First-cutting alfalfa, which is coarser and not so "washy" (laxative) as later cuttings, is preferred for horses, and its use fits well into the management program of many general stock farms.

Various experiments have been conducted to determine the feeding value of alfalfa hay for horses and mules. In one of these, Hudson (*547*) found that horses weighing 1,670 pounds and fed a daily ration of 12.23 pounds of corn and 17.91 of alfalfa when at medium to heavy work gained in weight, while similar horses on a ration of 8.02 pounds of corn, 6.23 of oats, and 19.59 of timothy hay lost weight. Also, the corn and alfalfa ration was 6 cents a day cheaper.

As the unlimited feeding of alfalfa hay has been said to result in softness, excessive sweating, heavy breathing, digestive disturbances, and filling (swelling) of the legs and hocks, its use should be restricted to about 1 pound or less daily per 100 pounds live weight of the animal. Alfalfa hay is especially valuable for brood mares, foals, and young stock.

Clover Hay

Bright clover hay that is free from dust is a good roughage for horses. Its content of protein, total digestible nutrients, minerals, and vitamins is high. Though various kinds of clovers are used for hay in different parts of the country, medium red is the one most widely favored. For light horses especially, a combination of timothy and clover is preferred to clover alone, as the quality of this mixture is often better than that of straight clover.

Soybean Hay

Soybean hay, an annual legume grown throughout most of the Corn Belt, may be used in the economical feeding of horses in many instances. This roughage is about equal to alfalfa hay in total digestible nutrients, is slightly laxative, and is particularly suitable for combination with corn or other concentrates that are high in carbohydrates. Soybean hay should be limited to about 50 percent of the roughage allowance; if it makes up the entire roughage ration, no more should be fed than is cleaned up in a reasonable time.

Grain Hay

Grain hay is extensively used on the Pacific coast and is economically important in the rations of horses throughout the Rocky Mountain area. Oats, barley, and wheat, when cut before maturity and cured properly, make hays that are palatable and nutritious. On account of the grain content, the amount of such forage fed should be restricted. Very little concentrate feed is needed with good grain hay, but it is desirable to include a feed relatively high in protein.

Miscellaneous Hays

Many other roughages are used for horses and mules in sections of the United States where they are commonly found and are of particular importance. Prairie hay of the range sections, for example, is an excellent roughage for horses, being about equal to timothy in feeding value. Hays from cowpeas, millet, and the sorghums are also used extensively in some areas, particularly in the South and Southwest.

Other Miscellaneous Roughages

Corn fodder, oat and wheat straw, and similiar roughages are economical feeds for horses, particularly when they are idle or at very light work. If hay is scarce and high in price, these roughages may also be used for other stock when supplemented by a limited feed of good legume hay. These cheap roughages, of course, are low in protein, minerals, and vitamins, furnishing bulky material principally. Some high-protein, laxative concentrate feed and sometimes a small quantity of good roughage should be fed with them. Work by Trowbridge (*1148*), showed that oat straw could be used as the only forage in a winter ration with corn, oats, and bran while horses were at light winter farm work. Oat straw alone, however, does not furnish enough nutriment for wintering horses (*286*). Moreover, the use of cheap, low-quality roughages should not be carried to the extreme. It should be confined primarily to work stock during idle seasons.

Silage

Silage should not be considered as the principal roughage for horses and mules, but rather as a supplement or appetizer. Corn silage, which is bulky, appetizing, and slightly laxative, is the only kind that has met with much favor. Too little work has been done with grass silage to draw definite conclusions. It is generally considered that the amounts of corn silage should not exceed 10 to 15 pounds daily per head for mature animals, although much larger amounts have been used satisfactorily in some instances. None but choice, fresh silage should ever be given, as severe losses from botulism have resulted from silage that did not fulfill these specifications. Frozen or moldy silage must not be used for horses or mules under any circumstances.

Alfalfa silage has more protein, energy, minerals, and vitamins than corn silage. Brood mares have been successfully wintered on alfalfa silage with a small amount of dry roughage, and it seems that this feed should be used to a greater extent.

Pasture

Although pasture is a natural feed for all horses and mules and is often sufficient for the maintenance of idle stock, it does not furnish enough nutrients for animals at steady work. It is, however, an excellent source of minerals and vitamins, and its use for work stock during periods of rest and idleness is an excellent means of toning up the system. During the summer work season particularly the use of a night and Sunday pasture for work stock is recommended, for it keeps the animals in better spirits and condition. The regular use of pasture is also a vitally important factor in the economical production of horses and mules, and brood mares and colts should have access to good pasture a large part of the year.

PREPARATION OF FEEDS

The grinding or crushing of concentrate feeds, except the small, hard grains (such as barley, wheat, rye, and the grain sorghums), is not generally recommended for work stock. The value of using such prepared feed depends on the cost of preparation, work conditions, and the age and condition of the animals. If prepared grains are fed, those that are crushed or coarsely ground, free of dust and not pasty, are preferred to finely ground grains.

Roughages such as corn stover and sorghum can generally be fed most economically to horses and mules when shredded or cut. The advisability of chopping, chaffing, or cutting hays of different kinds, however, depends largely on the quality and value of the feed and the cost of such preparation. Ordinarily, low-priced good-quality hay should not be prepared for feeding, but it may be economically advisable to chop, cut, or chaff poor-quality hays.

WATER

Water is essential to the horse and mule in various physiological processes and in supplying minerals. The average water consumption of a mature horse is variable, but it approximates 10 to 12 gallons daily (*92, 1224*). While horses will voluntarily drink more water when fed a protein-rich ration, they should be encouraged to use more water when eating dry, coarse roughage. Shy drinkers can often be made to drink more water by mixing a small amount of salt with the feed.

There is a diversity of opinion on the proper time and method of watering horses. Other things being equal, however, regularity and frequency of watering and working conditions are the most important considerations influencing water requirements. If the horse has been at moderate work, he usually may be watered before being fed and again offered water before being returned to work. It is dangerous, however, to water heavily a horse that has been deprived of water for a long time or that is very warm. During hot weather the horse should be watered often when at work and, if stabled, the last thing at night

MINERALS AND VITAMINS

An adequate hay and grain ration—that is, one containing legume or mixed hays and wheat bran—should supply sufficient minerals (except salt) for the mature work horse and mule. Because there is not enough in this feed, salt must be given regularly. While neither the kinds of vitamins nor the quantities required by horses and mules are known, the use of pasture and good-quality leafy hay and exposure to sunlight should provide sufficient vitamins for the work animal in most instances.

Mineral-deficiency problems in colt production are generally local in character. Where there are possibilities of a mineral deficiency in the available feeds, young stock especially should be provided with supplementary sources of minerals. If there is a known deficiency of calcium, ground limestone or oystershell flour may be used to correct it. If the ration is low in phosphorus, however, the addition of dried-milk products, steamed bonemeal, or dicalcium phosphate is recommended. In no instance should calcium supplements alone (ground limestone and oystershell flour) be added to rations low in phosphorus. This will increase the imbalance of minerals and accentuate the deleterious effects of the phosphorus deficiency. Where self-feeding is employed, the mineral supplements should be mixed with common salt and kept available in a self-feeder. For such purposes mixtures made in the following proportions by weight are recommended:

Calcium deficiency	2 parts calcium supplement. 1 part common salt.
Phosphorus deficiency	2 parts phosphorus supplement. 1 part common salt.
Calcium and phosphorus deficiency	2 parts calcium supplement. 2 parts phosphorus supplement. 1 part common salt.

Under free choice, varying amounts of these mixtures are consumed, depending upon pasture and feed conditions. Salt should also be fed ad libitum.

FEEDING UNDER WORK CONDITIONS

The proper nutrition of horses and mules when at work is a big factor in maintaining them in service for many years. Improper feeding for a short time may not cause much damage, but, if it is carried on over a long period or often repeated, it may result not only in lowered efficiency but in more serious consequences (*286*).

The kind and quantity of grain and hay required by work horses or mules depend among other things on the age, size, and condition of the animals and the kind, regularity, amount, and speed of the work performed. As the stomach capacity is relatively small, the amount of concentrates must be increased and the roughage decreased as the amount, severity, or speed of work increases. Although the exact amounts of feed are variable, a general guide is to allow 1¼ to 1⅓ pounds of grain daily with 1 pound of hay per 100 pounds live weight for horses at heavy work; about 1 pound of grain and 1 to 1¼ pounds of hay at medium work; and about ½ pound of grain and 1¼ to 1½ pounds of hay at light work. The maintenance ration for idle horses is considered later in this article.

The method of feeding has a great deal to do with the utilization of feed and the condition of the horse. The grain part of the ration for horses at work is usually divided into three equal feeds, given morning, noon, and night. If the horse does not clean up his grain in a reasonable length of time, the quantity should be reduced. About

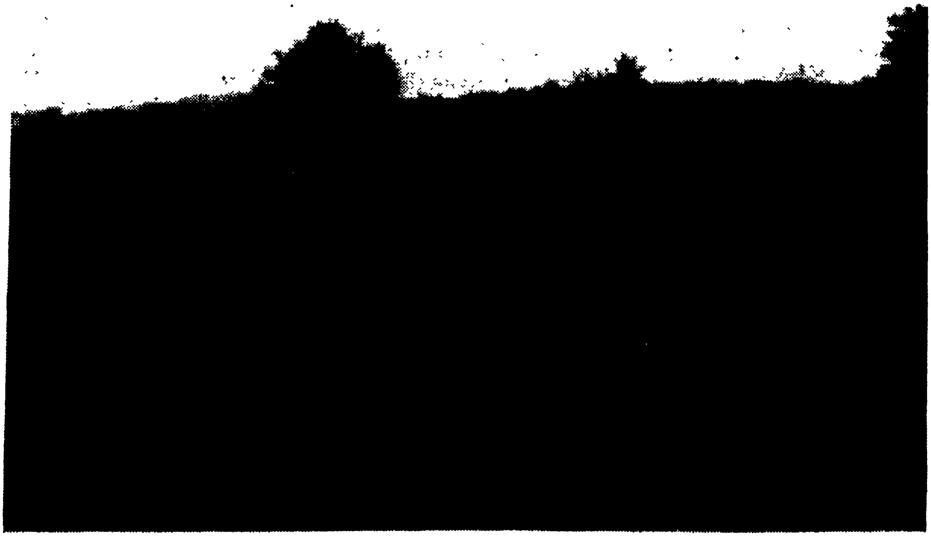

Figure 2.—**Horses on pasture provided with supplemental grain in a convenient feeding trough.**

two-thirds of the daily allowance of hay is given at night, with most of the remaining hay fed in the morning, leaving a very small allowance for a noon feed, if there is no hay left in the manger.

The quantity of roughage should be limited so that all edible forage will be cleaned up. Moreover, it is generally advisable to allow the horse to eat some hay before the grain at night. This will prevent his gorging on hay after eating the grain, thereby forcing the grain through the stomach too quickly for proper assimilation.

Overfeeding, rather than underfeeding, is common when horses are working irregularly. This is wasteful, expensive, and often has a harmful effect on the digestive system. When horses are working intermittently, the grain ration usually should be reduced about one-half, and only enough other feed given to keep them in fit condition. All feed should be given regularly, however. Turning work horses and mules regularly on pasture at night keeps the digestive system accustomed to succulent feed and decreases the quantity of grain and hay required. It is sometimes advantageous to provide equipment for feeding grain in the pasture (fig. 2).

SELECTING THE RATION

In selecting a ration for the farm horse or mule, the feeds should be confined principally to those grown on the home farm. Where the feed must be purchased, attention should be given to unit costs, inasmuch as it is usually possible to mix a satisfactory ration from a combination of available feeds on the market. In building the ration, one should remember also that not only is it important to consider the feed nutrients, including minerals, but that the ration must have enough bulk so that it is not too heavy, and that it should be made up of good-quality, palatable feeds, with enough variety to be relished by the animals.

In compiling the rations for the horse and mule at medium work given in table 2, theoretical requirements and feeds common to different parts of the United States have been considered.

As the rations suggested are for the average (1,000-pound) work horse, increase the quantity of feed in the ration by about one-fifth if the horse weighs 1,200 pounds, and by about two-fifths if the horse weighs 1,400 pounds. For example, in the case of the first ration, a 1,400-pound horse should receive 11.3 pounds of oats and 17 of timothy. In practical feeding this horse would get 4 quarts of oats three times daily, with about 12 pounds of hay at night and 5 in the morning. Sufficient hay probably would be left in the manger after the morning feed so the horse could eat a little before receiving his grain at noon, or a little hay should be given him then. If a horse weighs 1,000 pounds and is at heavy work, an increase of 3 pounds of grain (oats) daily (1 quart at each meal) and a slight reduction in the amount of hay fed should supply the necessary nutrients. However, it must be remembered that experimental work has shown that a ration of oats and timothy hay will not maintain the horse at hard work, so it would be best to use a combination of corn and oats under those conditions. When the horse is at light work, the grain should be reduced and the forage increased somewhat. An idle horse may often be carried on a ration consisting almost entirely of roughage, only enough grain being fed to keep the horse quiet when others in the stable that have worked are being fed.

TABLE 2.—*Suggested daily rations for the 1,000-pound horse or mule at medium work*

Feed	Quantity	Total dry matter	Digestible protein	Total digestible nutrients	Nutritive ratio, 1 to—
	Pounds	*Pounds*	*Pounds*	*Pounds*	
Oats (whole)	8	7.38	0.78	5.30	
Timothy hay	12	10.20	.41	5.99	
Total	20	17.58	1.19	11.29	8.5
Corn (ground ear)	10	8.44	.43	7.05	
Alfalfa hay	5	4.58	.57	2.67	
Timothy hay	5	4.25	.17	2.49	
Total	20	17.27	1.17	12.21	9.4
Corn (shelled)	7	6.10	.50	5.73	
Bran (wheat)	2	1.81	.25	1.23	
Timothy hay	10	8.50	.34	4.99	
Total	19	16.41	1.09	11.95	10.0
Corn (ground ear)	10	8.44	.43	7.05	
Red clover hay	10	8.71	.82	5.08	
Total	20	17.15	1.25	12.13	8.7
Corn (ear)	6	5.06	.26	4.23	
Oats (whole)	3	2.77	.29	1.99	
Bran (wheat)	.5	.45	.06	.31	
Mixed hay:					
Timothy	5	4.25	.17	2.49	
Clover	5	4.35	.41	2.54	
Total	19.5	16.88	1.19	11.56	8.7
Corn (shelled)	7	6.10	.50	5.73	
Soybean hay	5	4.58	.54	2.58	
Corn stover	7	6.25	.16	3.57	
Total	19	16.93	1.20	11.88	8.9
Barley (rolled)	8	7.23	.82	6.34	
Prairie hay (Colorado and Wyoming)	10	9.45	.44	5.82	
Total	18	16.68	1.26	12.16	8.7

WINTERING IDLE WORK STOCK

Maintaining farm work stock in healthy condition during the winter season is the first step toward fitting them for spring work. Open sheds adjacent to fields and pastures often make an ideal set-up for wintering purposes. Under this system horses and mules are provided with dry, comfortable protection during the idle season, yet have the benefit of the exercise obtained in getting a large part of their feed from fields or pastures. When large amounts of dry roughage are being used, it should be possible for the animals to obtain pure water at will. If necessary, a heater should be used to keep the drinking tank free from ice.

A horse should not be so fed during the winter that it becomes fat and soft. Nor, on the other hand, should it receive such poor care that it loses weight and vitality, becomes subject to disease, and is not in condition for spring work. A horse that is thin or run-down at the beginning of the winter or idle season should be gradually brought into thrifty physical condition by correct feeding over an extended period.

The liberal use of carbohydrate-rich roughages, supplemented with the right amount and kind of other nutritious feed, will maintain an idle horse properly during the winter. Cornstalk fields, grain-stubble fields, or pastures that have not been too closely grazed during the summer are very desirable sources of a large part of the winter maintenance feed. To supplement these feeds a limited amount of alfalfa, clover, or other palatable roughage may be used economically. The legumes are rich in protein, mineral matter, and vitamins, and supply materials needed to replace those lost in the natural wear of the body. Being somewhat laxative in effect, they also help to keep the digestive tract in good condition and are especially valuable for use in connection with straw and similar feed. In some instances, especially when it is not possible to feed a legume hay, a small quantity of grain is necessary to maintain idle horses in thrifty condition.

Corn silage, if fed with care, may be utilized in the winter ration of idle work horses. Its bulk, succulence, laxativeness, and the presence of carotene or vitamin A in good silage are of value when cheap, coarse roughages make up the major part of the ration.

PREPARING FOR SPRING WORK

During the fitting period preceding heavy spring work, horses and mules must be so conditioned that they will be able to convert the vitality and energy that have been stored up in the winter into full power each work day and even be prepared for an overload during the peak of heavy work. The amount of fitting necessary depends largely on the way the animals have been wintered. The condition of a horse that has been properly cared for in the open during the winter is more nearly ideal than that of the horse that has been kept in the stable. While the length of the fitting period varies, the average time usually allotted for it is 2 to 4 weeks. A horse that is either very thin or very fat requires a longer fitting period than one in thrifty condition with fair flesh. Also, a young horse, especially if just broken, requires a longer time for fitting and training than a mature horse.

While the use of coarse, nonsalable feeds is generally an economical practice during the winter, the horse should gradually be put on a ration of good-quality hay and a light feed of grain just before the fitting period begins. The quantity of grain is increased as the fitting period progresses, and when light work has commenced a 1,400-pound horse should be ready to utilize daily about 14 pounds of grain together with 14 or 15 pounds of fine-quality hay.

FEEDING THE BROOD MARE

Brood mares need a ration sufficient to supply both their own feed requirements and those of the fetus or suckling foal. A well-balanced ration containing sufficient protein and minerals is particularly needed. Brood mares should always be kept in thrifty condition, but it is important that they do not become too fat.

The right amounts of good-quality legume or mixed hay with a mixed grain ration will supply the nutritional requirements for the brood mare under work conditions. Idle brood mares generally need little grain if they are on good pasture or are supplied with a liberal amount of good-quality legume or mixed hay. In the winter, an open shed adjacent to pasture fields or paddocks is especially valuable in forcing brood mares to exercise and remain thrifty. A common practice in handling idle brood mares is to feed some good legume hay at night, a little grain or 10 to 20 pounds of corn silage in an open grain bunk in the morning, and coarse field roughage, timothy hay, or good straw to supply the balance of the feed.

The brood mare should not be fed heavily on grain or hay for the first 24 hours after parturition, although she may have a little hay and water from which the chill has been taken. The first grain fed should be light, such as a wheat-bran mash with a little cooked flaxseed meal in it. If confined to the stable, the mare should be kept on a limited ration for a number of days after parturition. A mixture of oats and wheat bran is satisfactory for the limited early feedings. Other feeds may be added later as the mare is returned to work or when the colt needs an increased milk supply (fig. 2). The use of good pasture or good-quality legume hay with mixed grain will stimulate milk production. Feeding too much grain at first, however, may produce too much milk, which may cause indigestion in the foal. The exact method of feeding the mare at this time depends upon her individuality and the existing conditions.

COLT PRODUCTION [7]

It is important that the foal be fed for optimum, efficient growth. The mare that is handled and fed properly will ordinarily supply the milk needs of the foal. The young animal will, however, begin to pick at grain, grass, and hay at an early age, and proper use of these feeds will determine to a great extent how well the colt will grow.

At a month or two of age the foal will start to take dry grains, if allowed to eat from the feed box of the dam. The use of ground oats, corn meal, and wheat bran for the mare at this time will assist in starting the foal on grain. Foals that are following their mothers on pasture may benefit from a supplementary ration of grain.

If a foal is getting plenty of nourishment from grain and grass or legume roughage, it will not be seriously set back at weaning (6 months). The foal should be eating about 4 pounds of grain daily at this age. During the weanling period (6 to 12 months) it is most important that the ration be sufficient in protein, minerals, and vitamins. The liberal feeding of good legume hay with some mixed grain is generally necessary for efficient growth. The thrifty colt should not be too fat but should be in good flesh.

The amount of grain necessary to produce efficient growth in colts may be limited if good roughage is available. Heavy feeding is not required, but steady growth should be maintained. In experiments with draft colts in Missouri, Trowbridge and Chittenden (*1149*) found that a limited ration produced a satisfactory 3-year skeletal growth. Also, they had less difficulty in keeping colts sound in their feet and legs on a limited grain ration than on a heavy ration. In his tests with colts of Belgian and Percheron breeding, Hudson (*549*) found that the use of limited amounts of grain and alfalfa hay with free access to straw in winter rations did not stunt the animals and that it had a greater effect on weights and condition than on skeletal development, although it did retard the latter. As a result of this work, it is Hudson's opinion that when feeds are cheap and the value of horses is high, the use of liberal rations may be advisable in order to hasten maturity, but that "where cheap pasture land is available and if hay and grain are high, it seems advisable to limit the feed of colts in the winter time and to take more time for their development."

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[7] This discussion is limited to feeding for production under ordinary conditions, as the feeding of the very young foal, especially the orphan, has been discussed in the article, The Nutrition of Very Young Animals (p. 501).

Edmonds (*305*), in tests with Percheron fillies in Illinois, found alfalfa hay fed with corn and oats gave such satisfactory results in developing weanlings and yearlings that there was little need of using purchased mill feeds when alfalfa could be grown on the farm. During the first winter an average of 5.674 pounds of grain and 4.266 of hay were required per pound of gain, while during the second winter feeding period an average of 9.228 pounds of grain and 12.99 of hay per pound of gain were needed.

Harper (*477*), at Cornell University, over a period of 10 years, found it required an average of 4,746 pounds of grain and 6,804 of hay to grow a farm colt to an average of 1,270 pounds the spring it was 3 years of age.

Edmonds and Crawford (*306*) state that weanling draft fillies made good gains in height and frame and kept thrifty on 2.3 pounds of grain and approximately 8 each of sheaf oats and soybean hay daily. During the second winter their daily consumption was 3.41 pounds of grain and over 9 each of sheaf oats and soybean hay. At about 2 years of age the fillies, in medium condition, averaged 1,484 pounds in weight.

In another test, Edmonds and Kammlade (*307*) found that limiting daily grain rations to 6.36 pounds of crushed oats and bran per head in one lot, and 5.4 of corn and bran per head in the other lot, with alfalfa hay and oat hay, gave satisfactory and economical results in the rate and quality of growth over the weanling and yearling periods. They also reported that the grain ration of 75 percent of crushed oats and 25 percent of bran proved the most satisfactory of those fed.

While the preparation of grain for mature draft horses is usually recommended only when concentrates like wheat and barley are fed, ground grains should be fed to the suckling foal. Caine (*184*), in an Iowa experiment, found that weanling colts made slightly larger gains on prepared oats than on whole oats and appeared to be fatter, and that colts fed rolled oats required less feed per pound of gain than those fed whole oats. Two years of work indicated no advantage in cutting hay for colts when good-quality hay was fed.

FATTENING FOR MARKET

Little experimental work has been done on the fattening of draft horses for market. It has been assumed by some that the principles for fattening other livestock are applicable to horses. To just what extent such principles may be applied to horses, however, is questionable, for in the case of horses heavy fleshing must be gained without sacrificing action or soundness or causing filling of legs and hocks.

In fattening the horse it is especially important to remember that the animal must be gradually accustomed to a heavy grain ration, and that the amount of feed must be increased very slowly to a maximum of about 2 pounds of grain for each 100 pounds of live weight.

During fattening, regular exercise for draft horses is important. Exercise is also highly essential in the fitting of light horses. Here the conditioning process is also a matter of hardening, and the horse is used daily in harness or under saddle. In fattening, the feeder of draft horses uses the lot for exercise. For the purchaser it would probably be much better if the same system were followed as with the light horse—daily use in harness—but economically this may not be possible. Obrecht (*865*), of Illinois, found that horses getting exercise made nearly one-half pound, or 20 percent, less gain in weight per day than did those not getting exercise, and that exercise increased the cost of finishing horses.

FEEDING LIGHT HORSES

The principles of feeding draft horses may be applied to light horses except that the latter require proportionately less hay and a little more grain per unit of body size. The qualities desired in light breeds are trimness, spirit, action, and endurance. These cannot be obtained with large, paunchy stomachs or lack of energy, which may result from excessive use of roughage.

Oats easily rank first among the grains for light horses, but for variety a small amount of crushed barley, wheat bran, cracked corn, or a commercial mixed feed may be used with oats. When corn or other carbohydrate feeds are fed, it is important that a little linseed meal or wheat bran be used. About 6 or 8 pounds of grain daily should be sufficient for the average light horse at medium or light work.

A mixture of one of the legume hays with timothy or other grass hay should be fed with the grain. During off-work seasons, much good will result if the grain ration is decreased somewhat and the roughage increased. Two or three months of pasture may often be used advantageously. In some instances a light grain ration may be desirable while the idle horse is on pasture. The advisability of using grain at this time is determined by the individuality and condition of the horse and related factors. In bringing the light horse into condition after a period of idleness the amount of roughage may be larger than when the animal is at steady work, as the "good doer" is one with a "good middle." Later the amount of hay should be reduced gradually and the grain increased before heavy use, sale, or show. Proper nutrition and management will tend to preserve a healthy condition year after year without the occurrence of summer sores and boils or the filling of hocks or fetlocks.

PRACTICAL NUTRITIVE REQUIREMENTS OF POULTRY

by Harry W. Titus[1]

THIS article discusses the results of some of the many studies on which modern poultry-feeding practices are based. It might be called the theory of poultry feeding, since it is concerned with the needs of the birds for the various nutritive elements in relation to reproduction, egg production, growth, and fattening. In another article, Practical Feeding of Poultry, these needs are translated into terms of actual feedstuffs.

BECAUSE of the greater economic importance of chickens, their nutritive requirements have been studied more extensively than have those of turkeys, guineas, pigeons, ducks, and geese. As a result of these studies, much dependable information about the quantitative nutritive requirements of chickens for growth, egg production, and hatchability has been obtained. (Figure 1 shows the interior of a modern laboratory in which chemical analyses are made for the control of poultry-nutrition experiments.) During the last 6 or 7 years, nutrition experiments conducted with turkeys have greatly increased in number and have added materially to our knowledge of the nutritive requirements of this species. Relatively little is known about the quantitative nutritive requirements of guineas, pigeons, ducks, and geese.

Qualitatively the nutritive requirements of chickens are in many ways the same as those of other animals, but quantitatively they are appreciably different. In other words, most animals require proteins, fats, carbohydrates, vitamins, and minerals for normal growth and reproduction, but they do not require the same relative quantities of these nutrients. Another difference is that the feed of chickens consists mostly of concentrates, whereas that of cattle, horses, sheep, and goats includes a rather large portion of roughages. In this respect chickens are more like swine than they are like any of the other domestic animals.

Ordinarily chickens are kept primarily for the production of meat and eggs, and for this reason they are seldom rationed; that is to say,

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Figure 1.—Interior of a modern laboratory, in which chemical analyses are made for the control of poultry-nutrition experiments.

instead of some suitable but fixed quantity of feed each day, they are usually fed all they can be induced to eat. Such full feeding is desirable because rapid growth is generally necessary for the economical production of meat, even though full-fed chickens utilize their feed somewhat less efficiently for growth than do chickens that consume appreciably less feed. Moreover, high egg production cannot be maintained if the feed supply is limited. For these reasons special care must be taken to balance the diets of chickens so that the economical production of flesh and eggs will be the ultimate result.

If considerably more protein, fat, and vitamins are supplied than are required, the chickens may be well but not economically nourished, because these three nutrients are usually the most expensive. It is not economical to force chickens to use protein and fat as sources of energy when the cheaper carbohydrates will serve the same purpose just as well, or even better; or to feed vitamins in gross excess of requirements; or, on the other hand, to supply too small quantities of minerals and vitamins and thus cause the chickens to use the protein in their diet less efficiently. It is more economical, however, to feed somewhat more protein and vitamins than may be required than it is to feed too little. This is also true of the mineral elements; but in attempting to supply adequate quantities of these there is likely to be a tendency to use too much because they are relatively cheap. Any great excess of minerals in the diet should be carefully avoided because in some cases such excess may be definitely harmful.

The nutritive requirements of chickens have been studied from several standpoints. What are the special requirements for high hatchability of the eggs that are to produce a new generation? What are the special requirements for high egg production, irrespective of hatchability? Are there special requirements for the growth of young stock? Finally, what are the requirements for fattening? At the risk of some repetition, this article will discuss nutrititive requirements in the order given in these four questions, bringing out differences in nutritive needs for each function. There will be a brief discussion of the nutrituve requirements of turkeys, and at the end, a table summarizing the available information for both chickens and turkeys.

EFFECT OF NUTRITION ON REPRODUCTION IN THE CHICKEN

Reproduction in the chicken is different in several ways from reproduction in the other farm animals. It is much more rapid, the embryo develops outside the body, and the food of the young is not prepared within the body of the mother. In the other farm animals the development of the embryo from its inception to its birth is influenced by the contemporary feed supply of the mother. In the chicken, as in all poultry, the feed supply of the developing embryo is fixed within a relatively short time after the egg is fertilized, and thereafter until hatching the development of the embryo is independent of the contemporary feed supply of the mother. Once a fertile egg is laid, the nutritional fate of the contained embryo is fixed, except insofar as it may be influenced by the egg's physical environment. Nevertheless, diet may affect reproduction just as markedly in chickens and other poultry as in cattle, sheep, and swine.

Three ways in which diet may affect reproduction in the chicken may be considered. (1) It may affect the quantity and fertilizing capacity of the sperm produced by the males and thereby affect the number of eggs fertilized; (2) it may affect the egg production of the females; and (3) it may affect the composition of the eggs and thus, in turn, the hatchability of those that are fertile.

DIET OF THE MALES

There is very little definite information about the effect of the diet of male chickens on their ability to produce sperm or on the fertilizing capacity of their sperm. Because a deficiency of vitamins A and E, either one or both, eventually leads to a failure of sperm production in the rat, it has been assumed that the same is probably true in other species. However, the writer has kept adult male chickens for more than 6 months on a diet that contained only about 10 International Units of vitamin A per 100 grams of feed—that is, about 6 to 10 percent of the minimum requirement of actively growing chicks—without observing any decrease in their sperm production. Similar results were obtained when a diet rendered deficient in vitamin E by treatment with a solution of ferric chloride in ether was fed for 5 months. Furthermore, Adamstone and Card (*15*) [2] found that male chickens could be kept on a diet deficient in vitamin E for at least a year, and in some cases for as long as 2 years, without losing their ability to fertilize. Thus it may be concluded that, although male chickens may eventually become sterile if kept on diets that are markedly deficient in either vitamin A or E or in both, they are able to subsist for a rather long time on such diets without losing their ability to fertilize.

It has been claimed that when male chickens are fed a diet in which the protein is derived from plant sources only they mate less frequently than when their diet contains some animal protein. Also, it has been reported that in one experiment the feeding of silage to male chickens tended to increase their sperm production. In both cases the experimental technique appears to have been faulty and incapable of yielding results from which reliable conclusions could be drawn.

The available experimental evidence indicates that it is difficult to decrease the sperm production or the fertilizing capacity of adult male chickens by dietary means, unless a given deficient diet is fed for a rather long time or unless the dietary deficiency is such that it affects the general health of the males. Also, there is no acceptable experimental evidence that the sperm production or fertilizing capacity of healthy male chickens can be increased by diet.

DIET AND HATCHABILITY

There is an abundance of evidence that egg production in the chicken is affected by diet. This phase of the subject is discussed in a section of this article which deals specifically with egg production (p. 799).

Some of the earliest observations regarding the hatchability of chicken eggs were: (1) That eggs laid during the winter did not hatch so well as those laid during the spring or summer; (2) that fewer eggs hatched if the chickens were confined than if they had access to sunshine and range; and (3) that the feeding of green feedstuffs generally improved hatchability. Research in poultry nutrition has supplied the explanation for these observations. Eggs produced during the winter did not hatch well chiefly because the chickens did not get enough vitamin D. For the same reason, fewer eggs hatched when the chickens were confined. Green foodstuffs tended to improve hatchability because they supply vitamin A and riboflavin (vitamin G), and other important nutritional factors as well. The discovery that cod-liver oil is an excellent source of vitamin D and that certain feedstuffs, such as alfalfa-leaf meal, are good sources of vitamin A and riboflavin has made it possible to improve greatly the hatchability of eggs laid during the winter or by chickens kept in confinement, even though no fresh green feed is supplied.

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[2] Italic numbers in parentheses refer to Literature Cited, p. 1076.

If the diet fed to chickens affects the composition of their eggs, it is logical to assume that it may also influence the development of the embryo and thus be an important factor in determining whether or not the eggs will hatch. There is ample evidence that diet may affect both the composition of eggs and their hatchability, and some of this evidence will now be presented and discussed.

Effect of Diet on the Composition of the Egg and the Embryo

The writer and his associates (*1140*) have obtained data that indicate that diet has at least a slight effect on the composition of both the yolk and the white of eggs and that the composition of the former is more readily changed than that of the latter. The percentage of protein and fat in the dry matter of the yolk is most readily affected, but the magnitude of the effect is small. McFarlane, Fulmer, and Jukes (*728*) determined the quantity of the three amino acids, tyrosine, tryptophane, and cystine,[3] in both the white and the yolk of eggs produced by hens that had received different diets and found no significant differences attributable to diet. Calvery and Titus (*187*) made somewhat more complete analyses of the white and yolk, and of the albumins and the vitellins,[4] of eggs laid by pullets that had been raised and kept on three diets which differed only in the source of the protein. The three sources of protein were (1) wheat middlings, (2) corn and corn-gluten meal, and (3) soybean meal. They observed no marked differences in the composition of the proteins of the eggs. Thus, according to the experimental evidence just cited, diet may affect the percentage of protein in both the yolk and the white but not the composition of the constituent proteins.

It has been demonstrated that both the percentage of fat in the yolk (*1140*) and the composition of the fat (*242*) may be influenced by diet. This was to be expected because the transference of fat from the feed to the maturing yolk may take place within 2 or 3 hours after the feed is ingested. According to Cruickshank's experiments (*242*), the chicken utilizes ingested fats for direct deposition in the egg even when abundant carbohydrate is present for the synthesis of normal fat; however, if there is a deficiency of carbohydrate a greater proportion of the ingested fat will be deposited in the egg. This same investigator concluded from her studies that although the degree of saturation and the proportion of the component fat acids in the egg could be considerably modified by the ingestion of unsaturated fat acids in the feed, the ingestion of saturated fat acids had relatively little effect in altering the normal composition of the mixed fat acids in the yolk.

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[3] See the article on Protein Requirements of Man (p. 173) for descriptions of the amino acids and their functions.

[4] The albumins and the vitellins are, respectively, the chief proteins of the white and of the yolk.

Several groups of investigators have demonstrated that the vitamin content of eggs may be influenced by diet. The quantity of vitamin A and of vitamin D may be made to vary over a rather wide range by varying the quantity in the diet. As was shown by Hart and associates (*492*) the vitamin D content of the eggs of chickens confined without access to sunshine may be increased as much as tenfold by subjecting the chickens to ultraviolet radiation. According to Russell and Taylor (*997*) the output of vitamin A in eggs may be as much as 32 percent of the quantity consumed in the feed, whereas only about 10 percent of the vitamin D in the feed is found in the eggs. However, De Vaney, Munsell, and Titus (*274*) were able to obtain a transfer of only a little more than 2 percent of the vitamin D from the feed to the eggs. There are few quantitative data on the relation between the output of the other vitamins in eggs and the quantity consumed; nevertheless it has been demonstrated that under experimental conditions the quantity of vitamins B_1 and E and of riboflavin in eggs may be influenced by diet.

Likewise, it has been shown that the mineral content of eggs and of the developing embryos may be affected by diet and, in some cases, by irradiation with ultraviolet rays. Buckner and Martin (*165*) observed that a limitation of the calcium in the diet of chickens caused thin shells to be formed but did not markedly affect the calcium content of the liquid portion of the egg. Buckner, Martin, and Peter (*167*) determined the calcium and phosphorus content of strong and weak chicks from hens of which some had received calcium carbonate in their diet and others had not. They found that both the quantity and percentage of phosphorus were approximately the same in strong as in weak chicks but that both the quantity and percentage of calcium were less in the weak than in the strong chicks. Insko and Lyons (*576*) were able to demonstrate that both the calcium and the phosphorus content of the embryos were less when no vitamin D was supplied than when the chickens received an adequate supply. Erikson and coworkers (*333*) obtained evidence that either cod-liver oil or sunshine tended to increase the inorganic phosphorus content of the egg yolk. And Hart and associates (*492*) found that the embryos in eggs from hens which had been irradiated with ultraviolet rays contained about twice as much calcium after 21 days of incubation as did the embryos in eggs from hens which had not been irradiated.

The quantity of some of the other mineral elements in eggs may also be affected by diet. Lyons and Insko (*705*) showed that the manganese content of the feed markedly affected the manganese content of the eggs. Erikson and coworkers (*332*) found that the addition of 2 percent of cod-liver oil to the basal diet of their hens raised the percentage of both copper and iron in the yolk of the eggs, and that sunshine, but not filtered sunlight,[5] had a similar effect. Strangely enough, however, the combination of sunshine and cod-liver oil did not increase the iron content as much as did the cod-liver oil alone, but it caused a greater increase in the copper content. It has been reported that merely adding iron compounds to the diet of chickens has no demonstrable effect on the iron content of the eggs, but it has been claimed that the feeding of plant materials rich in iron tends to increase the iron content.

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[5] Sunlight from which the ultraviolet portion has been excluded by filtering, as through ordinary window glass.

Several investigators have shown that the iodine content of eggs can be readily increased by increasing the iodine content of the diet. That the iodine content of eggs is ordinarily quite low may be inferred from the observation of Wilder, Bethke, and Record (*1220*) that the daily feeding per bird of only 2 and 5 milligrams of iodine in dried kelp, iodized linseed meal, or potassium iodide increased the iodine content of the eggs approximately 75 and 150 times, respectively.

While studying fluorine toxicosis (a disease condition due to fluorine poisoning) in laying hens, Phillips, Halpin, and Hart (*920*) obtained evidence that a part of the fluorine in the feed is transferred to the yolk of the eggs and that probably it is deposited in combination with the complex lipoids[6] of the yolks. Evidence that the highly toxic element, selenium, may also be transferred from the feed to the egg has been obtained by Poley, Moxon, and Franke (*929*).

Many other substances may be transferred from the feed to the egg, some of which are benzoic acid, certain fat-soluble dyes, and several of the plant pigments, such as xanthophyll, zeaxanthin, cryptoxanthin, and capsanthin.

Relation of Protein to Hatchability

Some of the earliest studies of the effect of dietary protein on hatchability were made by Parkhurst (*895*) who concluded that to obtain maximum hatchability, the diet should contain sufficient animal protein and vitamins. In later studies made by Byerly, Titus, and Ellis (*178*) no correlation was found between hatchability and the percentage of protein in the diet, but it was observed that certain protein supplements were significantly better than others in their effect on hatchability. The experiments of these workers clearly indicated that the second-week embryonic mortality was greater when the chickens were fed diets containing plant-protein supplements than when they were fed diets containing animal-protein supplements. They found that a large number of chondrodystrophic[7] embryos were obtained when the former diets were fed and concluded that some of the protein supplements which they had studied were deficient either in some vitamin or in the quality of the protein itself. They also found that the chondrodystrophy was eliminated when the chickens were permitted to have access to range. This latter finding explains in part the apparently contradictory observation made in earlier studies by Parkhurst and Rhys (*896*) that the kind of protein supplement had little effect on hatchability, because in the experiments of these workers the chickens had access to grass runs. In this connection it may also be stated that Parkhurst and Rhys observed that hatchability was better when mixed protein supplements were used than when the sole protein supplement was meat-and-bone meal.

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[6] Lipoids are fats or fatlike compounds containing nitrogen.

[7] Exhibiting an abnormal condition of the bones, presumably due to a defective or faulty nutrition of the cartilage of the bone. In this case the chondrodystrophy was characterized by a shortening of the leg bones and the development of a parrotlike beak.

Further evidence that proteins from different sources may affect hatchability differently has been obtained by Titus and associates (*1141*), who found that when liquid stick (the concentrated liquor from the steam rendering of fatty animal material) was used as a protein supplement, the egg production was almost as good as when a high-grade meat scrap was used, but the hatchability of the eggs was very much poorer. A mixture of blood meal and stick had an even more pronounced and deleterious effect on hatchability than did stick alone. With both supplements embryonic mortality increased throughout the incubation period, but the increase was most pronounced during the last 11 or 12 days. Smith and Branion (*1075*) found that a mixture of liver meal and dried buttermilk affected hatchability more advantageously than did either one alone and suggested that this combination of protein supplements supplies the same essentials as does good grass range.

In considering the effect on hatchability of the protein in the diet, it is of some significance that neither McFarlane, Fulmer, and Jukes (*728*) nor Calvery and Titus (*187*) were able to demonstrate that the source of the dietary protein has any appreciable effect on the composition of the proteins of either the white or the yolk of the resulting eggs. However, the observations of Patton (*898*), that when embryonic mortality is associated with chondrodystrophy the embryos contain less than the normal quantity of glycine (one of the amino acids), indicate that hatchability may be influenced by the protein in the diet or by factors which affect protein metabolism. It has been suggested that the difference between plant-protein and animal-protein supplements in their effect on hatchability is due to the fact that the latter contain one or more vitamins not present in the former. It is known that animal-protein supplements are, as a class, better sources of riboflavin (vitamin G) than are plant-protein supplements. However, in the study of packing-house byproducts made by Titus and associates (*1141*), the stick and high-grade meat scrap they used had very nearly the same riboflavin content, but the hatchability was very much lower on the diets that contained the stick than on those that contained the high-grade meat scrap.

The effect of the quantity of protein in the diet on the hatchability of the eggs produced has received relatively little attention. Heiman, Carver, and St. John (*501*) concluded that the diet of laying hens should contain about 15 percent of protein, but in their experiments the best hatchability was obtained when the diets contained about 16 percent. The writer found that if the protein content of the diet is reduced sufficiently, the hatchability is decreased, and concluded from his experiments that for both good egg production and hatchability the diet should contain about 16 percent of protein of good quality.

Fat and Carbohydrate in Relation to Hatchability

The effect on hatchability of the kind or quantity of fat and carbohydrate in the diet appears not to have been studied. However, in view of the fact that Titus, Byerly, and Ellis (*1140*) and Cruickshank (*242*) found, respectively, that the percentage of fat in the yolk and the composition of the fat may be influenced by diet, the study of the effect of dietary fat on hatchability should yield some valuable results.

Vitamins and Hatchability

Vitamin A

It is generally agreed that vitamin A is required for good hatchability, but there is conflicting evidence about the quantity required. This state of affairs is due in part to the fact that different investigators have used different breeds of chickens and have measured the requirement in different units, and that there is some disagreement about the factors that should be used in converting from one system of units to another. The writer interprets the data of Russell and associates (*996*) as indicating that at least 840 International Units of vitamin A per 100 grams (about 3.5 ounces) of feed are required for the heavy production of eggs of high vitamin content, especially if good hatchability is to be maintained. According to Bearse and Miller (*73*) a diet supplies enough vitamin A for breeding stock if it contains about 700 International Units per 100 grams. However, it may be concluded from the studies of Sherwood and Fraps (*1057*) that the diet should supply about 1,050 International Units per 100 grams of feed for the maintenance of health and the production of eggs of high vitamin A content. Unfortunately, most of the experimental work has been done for the purpose of determining the minimum rather than the optimum requirement of vitamin A for good hatchability, and in practical poultry husbandry the optimum requirement rather than the minimum requirement should be supplied. According to the writer's experience, the optimum level of vitamin A intake is about 1,040 International Units per 100 grams, or about 4,720 International Units per pound, of feed, and this value is in good agreement with that deduced from the work of Sherwood and Fraps (*1057*).

Vitamin B_1

Payne and Hughes (*899*) concluded that a deficiency of vitamin B_1 will reduce hatchability; but their vitamin B-deficient diets were also deficient in riboflavin (vitamin G), and so their conclusion cannot be accepted. Ellis and associates (*382*) also used a diet that was deficient in vitamin B_1 and riboflavin, and they found that only about 15 percent of the resulting eggs hatched and that the hatchability was not greatly improved by adding good sources of vitamin B_1 (rice bran and rice middlings) to the diet. Chicks hatched from the eggs produced on this deficient diet showed symptoms of polyneuritis soon after hatching, but failed to show the symptoms when rice byproducts were added. In view of the fact that some of the eggs hatched on a diet so deficient in vitamin B_1 that there was a high incidence of polyneuritis among the hens to which it was fed, it must be concluded tentatively that the essentiality of vitamin B_1 for hatchability is doubtful, or that only an exceedingly small quantity of this vitamin is required.

Vitamin C

There is good evidence that the chicken is able to synthesize vitamin C, and hence it may be assumed that it requires this vitamin for the performance of its normal body functions. It has been demonstrated by several workers, however, that the chicken does not require preformed vitamin C in its diet.

Vitamin D

Hughes, Payne, and Latshaw (*559*) were among the first to show that vitamin D is necessary for the production of hatchable eggs. Carver and associates (*193*) have reported that although 67 International Units of vitamin D[8] per 100 grams of feed are sufficient for good egg production, 135 units per 100 grams of feed are required for good hatchability. Bethke and associates (*98*) found that only 54 International Units of vitamin D per 100 grams were enough for good hatchability. Murphy, Hunter, and Knandel (*830*) reported that Single Comb White Leghorn pullets, which had been confined without access to sunshine but which had received 78 International Units per 100 grams of feed from the time of hatching, gave satisfactory results from the standpoint of both egg production and hatchability. From unpublished observations, the writer concludes that the optimum level of vitamin D intake for heavy egg production is about 120 International Units per 100 grams or about 540 per pound of feed, and that if there is enough vitamin D in the diet to support heavy egg production there is enough for good hatchability.

The possibility of supplying too much vitamin D is demonstrated by the researches of Branion and Smith (*148*) and of Titus and Nestler (*1144*). The first two workers found that an excess of vitamin D from viosterol (a solution of irradiated ergosterol in oil) markedly decreased hatchability. The second two workers confirmed this finding and demonstrated that an excess of vitamin D from cod-liver oil has the same effect.

Vitamin E

That vitamin E is essential for hatchability was first demonstrated by Card, Mitchell, and Hamilton (*190*) in 1930. Five years later Barnum (*62*) concluded from his studies that vitamin E deficiency in the chicken is manifested by an increase in the first-week embryonic mortality. There are no reliable data on the quantitative vitamin E requirement for good hatchability. The available evidence on the subject indicates, however, that the ordinary poultry diets contain enough vitamin E to support good hatchability.

Riboflavin (Vitamin G)

Halpin, Holmes, and Hart (*1242*) observed that hens may lay the normal number of fertile eggs and appear to be healthy even though their diet is deficient in vitamin G, but that as a result of the deficiency many of their eggs fail to hatch. Bethke, Record, and Wilder (*99*) concluded that embryonic development of the chick is dependent on the vitamin G (complex) content of the egg. The quantitative vitamin G requirement for good hatchability has been determined recently by Davis, Norris, and Heuser (*268*). These workers concluded that about 245 micrograms[9] per 100 grams, or about 1,110 per pound, of feed are required; and this value is in good agreement with the earlier estimate of 230 micrograms per 100 grams of feed made by Norris and associates (*862*).

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[8] The standard unit for the measurement of vitamin D potency is the International Unit. Assays of the potency of sources of vitamin D are made, according to the definition of the International Unit, with rats; but chickens do not react to all sources of vitamin D in the same way as do rats. Accordingly, the Association of Official Agricultural Chemists has devised a method of assay in which chicks 1 or 2 days old are used as the test animals. When the source of vitamin D being assayed is pure cod-liver oil, 1 A. O. A. C. chick unit is equal to 1 International Unit, but when other sources are being assayed, 1 A. O. A. C. chick unit may be equal to as many as 100 International Units. The potency of cod-liver oil or other sources of vitamin D that are to be used in the feeding of chickens should be stated in terms of A. O. A. C. chick units.

Unidentified Factors

When a diet already adequate in vitamins A, D, E, and G, which are known to affect hatchability, is supplemented by certain animal proteins or by green grass, the hatchability of the eggs is significantly improved. This was established by Nestler and associates (*846*) and by Hunt, Record, and Bethke (*562*). Their work indicates that some unidentified factor in these feeds brings about the improvement. The unidentified factor is lacking in dried whey, since hatchability was not improved when this was used as the supplement.

Effects of Minerals on Hatchability

Calcium and Phosphorus

The importance of an adequate dietary supply of calcium for good hatchability was demonstrated by Buckner, Martin, and Peter (*166*, *168*). These workers concluded that the addition of calcium carbonate to the diet of chickens is essential for the maintenance of the hatchability of their eggs. That too much calcium may adversely affect hatchability was shown by Titus and associates (*1142*). These workers also found that the effect of an excess of calcium is conditioned by the phosphorus content of the diet and that as this is increased it is necessary to increase the calcium content also, if good hatchability is to be obtained. Suitable levels of calcium and phosphorus intake for both good egg production and hatchability are given farther on (p. 814).

Manganese

Shortly after it was found by poultry-nutrition investigators at Cornell University that perosis[10] was due, at least in major part, to a deficiency of manganese, Lyons and Insko (*705*) reported that the hatchability on a basal diet which contained only about 6 parts per million of manganese was only about 5.2 percent and that the embryos exhibited many of the symptoms of chondrodystrophy which had been described by Byerly and associates (*179*). When, however, the same diet was fed after 40 parts per million of manganese had been added to it, the hatchability was increased to 49.4 percent and chondrodystrophy was eliminated. Lyons and Insko thus demonstrated that manganese plays an important role in the embryonic development of the chicken. Their work and that of others indicates that for good hatchability the diet should contain about 50 parts per million of manganese.

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[9] The standard unit for the measurement of vitamin G (riboflavin) potency is the microgram, or gamma, which is one-millionth of a gram or slightly less than one twenty-eight-millionth of an ounce. Most of the early assays of the vitamin G potency of poultry feeding stuffs were made by research workers in poultry nutrition at Cornell University. In these assays young growing chicks were used as the test animals and a unit of measurement which was dependent on the growth of the chicks was devised. This chick-growth unit has frequently been referred to as the Cornell chick unit. Later work showed that the original Cornell chick unit of vitamin G is approximately equal to 1 microgram of riboflavin.

[10] Perosis is a condition in which there is faulty development of the skeleton, which is most readily observed in the bones of the legs. The symptoms are enlargement of the hock joints, bending and rotational twisting of the leg bones, and in advanced cases a slipping of the tendons from their normal position. The condition has been called "hock disease" and "slipped tendons."

Selenium

The possibility that certain mineral elements, when ingested with the feed, may adversely affect embryonic development was clearly shown by Poley, Moxon, and Franke (*929*). These workers found that when a diet that contained about 15 parts per million of selenium (supplied by naturally grown grain) was fed for a period of 5 weeks, hatchability progressively decreased to zero. They also observed that 6 days after feeding of normal grain was instituted, the apparently toxic effects on embryonic development and on hatchability disappeared. The practical importance of the findings of Poley, Moxon, and Franke is somewhat obscure at the present time, but it may be pointed out that there are a number of areas throughout the world in which the soil contains significant quantities of selenium.

Sunshine and Hatchability

It has been known for a number of years that permitting chickens to have access to sunshine has a beneficial effect on the hatchability of their eggs. The major part of this effect is undoubtedly due to the fact that when animals receive sunshine they are able to make at least a part of the vitamin D that they require. However, Smith (*1074*) obtained evidence that there is a difference in the degree to which sunshine improves the hatchability of eggs depending on the kind of protein supplement in the feed. This raised the question as to whether sunshine supplies another factor than vitamin D that is necessary for good hatchability. Somewhat later Byerly and associates (*180*) demonstrated that this was the case. With the diet used in their experiments, egg production was significantly greater in pens receiving direct sunlight than in confined pens adequately supplied with cod-liver oil. The exact nature of this factor has not yet been established.

Adaptation to Diet and the Effect of Age and Stage of Development on Hatchability

Byerly, Titus, and Ellis (*177*) studied the hatchability of the eggs produced by pullets that received diets in which the protein was derived solely from (1) wheat middlings, (2) corn and corn-gluten meal, and (3) soybean meal. Some of the pullets were fed these diets from the time they were hatched and some only after they had been raised to sexual maturity on a well-balanced diet. The hatchability of the eggs from the pullets that were raised on these diets was significantly greater than that of the eggs from the pullets that were raised on the well-balanced diet. These workers concluded that this must mean that, of the birds reared on the diets in which the protein was derived from these single sources, those that were less able to utilize such restricted sources of protein died before they reached maturity. In any case, the writer suggests that it is desirable to feed to breeding stock diets composed of essentially the same feedstuffs as were used in the diet on which the chickens were raised.

On the other hand, the possibility must not be overlooked that the age or stage of development of chickens may affect their ability to utilize certain diets. Byerly and associates (*180*) found that if pullets were fed diets in which the chief protein supplement was soybean meal, the percentage of hatchability of the resulting eggs progressively decreased from October to January, after which it again increased to relatively high levels. These same workers also found (results unpublished) that if the same diet were fed to yearling hens, there was no marked decrease in hatchability from October to January. Moreover, Titus and associates (*1142*) observed that pullets and hens do not react in the same way to high and low levels of calcium intake. In their experiments the hens laid more eggs than the pullets on the least calcium but on the diets containing the most calcium the pullets laid more than the hens. They found that the deleterious effect of a high level of calcium intake on hatchability was more pronounced in the eggs from hens than in the eggs from pullets.

Time of Occurrence of Embryonic Mortality

Byerly, Titus, and Ellis (*177*, *178*) and Titus and associates (*1141*, *1142*) have made extensive studies of the relation between the time of occurrence of embryonic mortality and diet. They observed that when the protein of the diet was derived chiefly from products of plant origin there was a marked increase in the second-week embryonic mortality. They also found that the percentage of embryonic mortality increased during the last 3 days of incubation if the calcium intake was increased to excessive levels and that this increase was greater when the phosphorus intake was 0.9 percent of the diet than when it was 1.2 percent. These same workers also observed that the inclusion of stick, or of a mixture of stick and blood meal, in the diet as the chief protein supplement markedly increased the mortality throughout the entire period of incubation, but that the increase was greatest after the tenth and eighth days, respectively.

It was found by Insko and Lyons (*576*) that the third-week embryonic mortality, which they observed when a diet deficient in vitamin D was fed, was markedly decreased when vitamin D was supplied. Lyons and Insko (*705*) also observed that the embryonic mortality during the third week was reduced more than 60 percent when manganese was added to diets that contained only a very small quantity of this element.

As previously noted, Barnum (*62*) associated increased first-week embryonic mortality with vitamin E deficiency of the diet.

From the information available on the time embryonic mortality takes place it is evident that the mortality occurring during the third week may be caused by several different factors and thus is attributable to cumulative effects. On the other hand, the second-week mortality and, perhaps to an even greater extent, the first-week mortality, when attributable to diet, seem to be due to immediate causes.

NUTRITION AND EGG PRODUCTION IN THE CHICKEN

The egg of the chicken is normally a complete and balanced combination of all the nutritive elements required for the full development of the chick embryo. It contains everything necessary for the formation of blood, nerve, and brain; muscle, tendon, and bone; skin, nail, and feather; and enough nourishment to enable the chick to break through its shell and survive for several days without feed. Moreover, the chicken egg is highly prized as human food.

The egg is readily separable into three parts—the white, the yolk, and the shell. The white in turn may be separated into four parts—an outer envelope of fluid white, an inner envelope of firm white, an inner envelope of fluid white, and a small portion of firm white that is attached to the yolk. The yolk consists of alternate, concentric layers of white yolk and yellow yolk. The shell is made up of several layers of calcium carbonate and an outer cuticle, or skin. Attached to the inner surface of the shell and separating the shell from the white are the outer and inner shell membranes. The white is separated from the yolk by the vitelline membrane which completely surrounds the latter.

COMPOSITION OF THE EGG

On an average, the white accounts for about 58 percent by weight of the whole egg, the yolk for about 32 percent, and the shell for about 10 percent. The white consists of nearly 87 percent of water, nearly 12 percent of protein, and very small quantities of fats, sugars, minerals, and other substances. The yolk contains about 49 percent of water, about 32 percent of fat, about 17 percent of protein, and comparatively small quantities of sugars, minerals, and other substances. The shell consists mostly of calcium carbonate but contains some organic matter, water, and mineral substances other than calcium carbonate.

The proteins in eggs supply all the amino acids necessary for growth and maintenance. The fats contain an appreciable quantity of at least one of the so-called essential fat acids, i. e., linoleic acid. The mineral elements always present in eggs include calcium, magnesium, potassium, sodium, iron, aluminum, manganese, zinc, copper, lead, silicon, phosphorus, sulfur, chlorine, iodine, and fluorine; and traces of arsenic, boron, titanium, and vanadium have also been found.

In general, eggs are a good source of riboflavin (vitamin G), and a fair source of vitamin A and vitamin D; they also contain some vitamin B_1, vitamin E, and vitamin K. Although the fresh egg contains no vitamin C, it can be demonstrated that appreciable quantities are formed after the fourth or fifth day of incubation.

PHYSIOLOGICAL PROCESSES OF EGG FORMATION

The organs primarily concerned with the formation of the egg are the ovary and the oviduct. A short time before egg production begins several of the ova begin to grow, the calcium content of the blood increases two to two and one-half times, and finally one of the ova is released as a matured yolk. Upon its release from the ovary, or shortly thereafter. the yolk is grasped by the mouth of the oviduct and slowly forced toward the vent. As the yolk passes through the oviduct the white is laid down and then the shell is formed. By the time the egg reaches the end of the oviduct it is complete and ready to be laid. Between 14 and 16 hours are required for completing the egg after the ova is released. The time that elapses between the completion and the laying of an egg may vary from 10 to 14 hours;

however, when a chicken is producing heavily, about 24 to 26 hours elapse between the laying of consecutive eggs in a clutch.

The various physiological processes involved in the development of the ova and the oviduct, and in the laying down of the white and the shell, are not fully known. However, there is some evidence that a hormone secreted by the anterior lobe of the pituitary gland starts the development of the ova in the ovary and, in turn, the ovary appears to secrete a hormone that stimulates the development of the oviduct and keeps it in a functioning condition after it is fully developed. The stimulus for the laying down of the white and the shell appears to be largely mechanical, that is to say, the presence of the yolk or of any small object in the oviduct first causes the white to be secreted and then the shell to be formed.

Egg production may be quite markedly affected by the treatment of the chickens, by interruptions of the feed supply, and by environmental temperatures. Frequent handling of chickens, until they become accustomed to it, tends to decrease egg production. Moving them from one environment to another, especially during the early part of the molt, or just before, tends to cause a break in egg production. During the period of the molt, egg production is usually greatly reduced and in many instances is stopped entirely. Irregularity of feeding and the temporary withholding of the feed adversely affect production. Sharp drops in temperature may cause egg production to cease entirely for a few days or even several weeks. During periods of high temperature there is a tendency for the weight of the eggs to decrease, and if the temperature is sufficiently high egg production may decrease or even stop.

NUTRITIVE REQUIREMENTS FOR EGG PRODUCTION

Although the potential egg-laying capacity of a chicken is largely determined by its inheritance, the number of eggs laid, within this capacity, is dependent on the quantity and kind of feed eaten. A part of the feed consumed by a pullet is used for growth and the remainder for maintenance and egg production. In yearling and older hens, most of the feed is used for the last two purposes, but some is used for regaining the weight lost during the molt.

The economic maintenance requirement (p. 431) of White Leghorn pullets weighing 4 pounds is between 0.145 and 0.160 pound of feed per bird per day, and for pullets weighing only 3.6 pounds it is between 0.134 and 0.148 pound per bird per day. The economic maintenance requirement of chickens of the heavier breeds is appreciably greater; for example, in the case of Rhode Island Red pullets that weigh 5½ pounds it is between 0.205 and 0.227 pound per bird per day, and for pullets that weigh only 5 pounds it is between 0.186 and 0.206 pound per bird per day. The economic maintenance requirement of hens of any given live weight is essentially the same as that of pullets of the same live weight.

It has been found that after the growth and maintenance requirements have been taken care of, the quantity of feed required to produce an average 2-ounce egg is between 0.078 and 0.1 pound, or on an average about 0.09 pound. Apparently, the first determination of the quantity of feed required, in addition to the economic maintenance

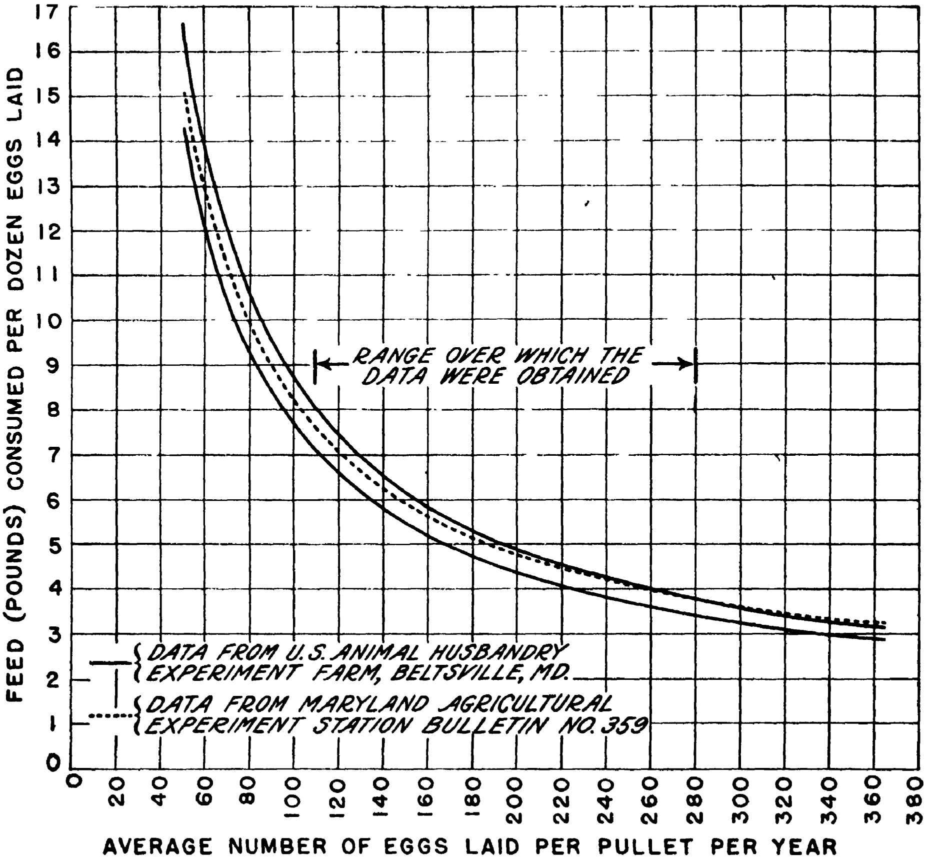

Figure 2.—The more eggs a pullet produces in a year, the less feed is required per dozen eggs. A White Leghorn pullet producing 100 eggs a year consumes almost twice as much feed per dozen eggs as a pullet producing 200 eggs a year. (Data obtained in different years from two different lots of White Leghorn pullets at the U. S. Animal Husbandry Experiment Farm, Beltsville, Md., and from Md. Agr. Expt. Sta. Bull. 359 (*1178*). Data graduated by the method of least squares.)

requirement, to produce an egg was made in 1928. This quantity of feed was found to be about 0.089 pound (*1139*). Ten years later Brody and others (*155*) of the Missouri Agricultural Experiment Station made a detailed study of the efficiency of feed utilization for egg production and found this quantity to be about 0.087 pound. The agreement between the two values is exceptionally good, but undoubtedly accidental.

Feed Cost and Efficiency of Egg Production

A more or less fixed quantity of feed is required per day for the maintenance of a laying chicken, no matter what its rate of egg production may be. The quantity required for the making of an egg is always less than this daily maintenance requirement. It follows that the total feed cost per egg is much less when the average production of a flock is high than when it is low. It also follows that the efficiency of egg production, that is, the number of eggs produced per unit weight of feed consumed, increases as egg production increases.

The relation between the feed cost of a dozen eggs and the average annual egg production is shown in figure 2, in which the feed consumed per dozen eggs is plotted against the average number of eggs laid per bird per year. According to these curves a White Leghorn pullet will consume between 7.7 and 8.7 pounds of feed per dozen eggs, if she lays 100 eggs per year, but only from 4.4 to 4.9 pounds, if she lays 200 eggs. This clearly demonstrates the importance of having chickens that can be depended on to produce a large number of eggs.

Figure 3 shows the relation between the efficiency of egg production and the average number of eggs laid per bird per year. It shows very definitely that chickens of the heavier breeds lay fewer eggs per pound of feed than do those of the lighter breeds and indicates that pullets lay more eggs per pound of feed than do hens. Notwithstanding, it must be recognized that different strains of the same breed may be appreciably different in their ability to utilize feed for egg production, as is suggested by the three curves in figure 2.

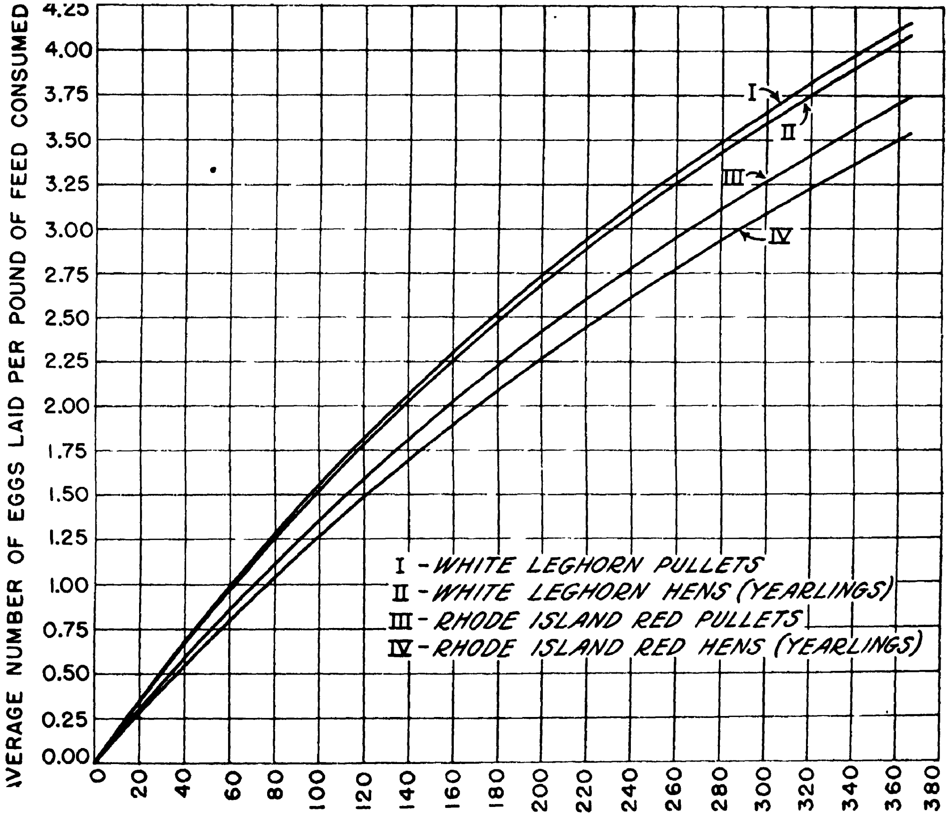

Figure 3.—The breed and the age of chickens affect the efficiency of feed utilization for egg production. Pullets are more efficient producers than hens; the lighter breeds are more efficient than the heavier breeds. (Data from U. S. Animal Husbandry Experiment Farm, Beltsville, Md., graduated by the method of least squares.)

Specific Requirements

It has been demonstrated several times that it is possible to compound two diets on which the egg production will be practically the same but on which the hatchability will be very different. It has been found, however, that the eggs of chickens that lay a large number tend to hatch better than those of chickens that lay a much smaller number. This suggests that it is always best to feed diets that will permit the chickens to produce eggs of high hatchability, because poor hatchability may be the result of a dietary deficiency too slight to decrease egg production but sufficient gradually to undermine the health of the chickens. The nutritive requirements for good hatchability have already been discussed; the specific nutritive requirements of chickens for egg production follow.

That egg production is dependent on the nature of the diet may be demonstrated easily in a number of ways. If nothing but grain is fed, a high level of egg production cannot be maintained because grain usually does not supply enough protein and that which it does supply is not of suitable quality. If the diet contains too little calcium, egg production ceases rather promptly; and if the chickens do not get enough vitamin D they cannot properly use a supply of calcium that would otherwise be adequate. Also, if the diet is deficient in vitamin A, the general health of the chickens will be adversely affected and egg production will decline or cease entirely. According to the existing knowledge about poultry nutrition, if the diet furnishes enough protein of good quality and adequate supplies of the necessary minerals and vitamins, it is suitable for egg production, provided it contains no harmful ingredients.

Protein Requirements

An egg that weighs 56.7 grams (2 ounces) contains slightly more than 7 grams of protein of very high biological value, or quality; to produce such an egg a chicken requires from 10.5 to 12.5 grams of digestible protein; and to supply this, 12.5 to 15 grams of feed protein of good quality is required. Inasmuch as the chicken has a rather limited capacity for storing protein that can be used for making eggs, the feed consumed each day should furnish not less than 12.5 grams of protein of good quality, if a constantly available supply thereof for making eggs is to be maintained.

It has been found that very good egg production—200 eggs or more per year—may be obtained on diets containing as little as 12 to 13 percent of protein. In spite of this, it has been observed that egg production, especially in pullets, tends to increase as the protein content of the diet is increased from 13 to 18 or even 20 percent. Several groups of investigators have found that both live weight and good egg production can be maintained on diets containing 15 percent of protein. It is safer, however, to rely on a protein content between 16 and 17 percent. This is particularly true in the case of pullets during their first 4 months of egg laying, when protein is required for both growth and egg production.

What has just been said about suitable percentages of proteins in the diet for egg production applies only when the protein is of good quality. To insure that the protein will be of suitable quality, not less than 20 percent of it should be from feedstuffs of animal origin such as liquid skim milk, liquid buttermilk, dried skim milk, dried buttermilk, meat scrap, and fish meal.

Mineral Requirements

A chicken that lays 200 eggs per year puts into those eggs about 400 grams of calcium or about 13 to 15 times as much as there is in her entire body. If the diet is deficient in calcium, a chicken can draw on its skeleton for only enough calcium to make about 3 or 4 eggs. From this it is evident that the calcium requirement of laying chickens is very high and that the feed must supply virtually all the calcium that goes into the eggs.

The proper percentage of calcium in the diet is dependent on (1) the number of eggs laid per bird, (2) the quantity of feed consumed, and (3) the phosphorus content of the diet. Inasmuch as the laying chicken can readily adapt her physiological processes to diets that contain somewhat more calcium and phosphorus than she needs, it is possible to set up standards for the calcium and phosphorus content of the diet that will be applicable under all ordinary conditions. Table 1 shows approximately how much calcium diets of different phosphorus content should contain.

Table 1.—*Corresponding approximate percentages of phosphorus and calcium for all-mash diets and for laying mashes with which grain is to be fed*

All-mash diets		Laying mashes (with which grain is to be fed)		All-mash diets		Laying mashes (with which grain is to be fed)		All-mash diets		Laying mashes (with which grain is to be fed)	
Phosphorus content	Calcium content	Phosphorus content	Calcium content	Phosphorus content	Calcium content	Phosphorus content	Calcium content	Phosphorus content	Calcium content	Phosphorus content	Calcium content
Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0.6	1.9	0.8	3.7	0.9	2.3	1.1	4.1	1.2	2.7	1.4	4.4
.7	2.0	.9	3.8	1.0	2.4	1.2	4.2	1.3	2.8	1.5	4.6
.8	2.1	1.0	3.9	1.1	2.5	1.3	4.3				

Occasionally the feed of laying chickens may contain too little phosphorus, especially if it contains very little dried skim milk, dried buttermilk, meat scrap, meat-and-bone scrap, or fish meal. In case the total phosphorus content of the diet is appreciably less than 0.7 percent, enough steamed bonemeal should be added to bring it up to at least this value.

Ordinarily the feed consumed by laying chickens does not contain enough salt unless some is added. The quantity to add depends to some extent on the other ingredients of the feed mixture. If the feed mixture contains as much as 15 percent of meat scrap, meat-and-bone scrap, fish meal, or any combination of these feeding stuffs, not so much salt need be added as when other protein supplements are used. In any case, if the total feed contains about 0.5 percent of added salt, all the salt requirements of the chickens will be fully met and there will be little likelihood of any harmful excess.

It has been found that many of the usual feed mixtures fed to poultry may not contain enough manganese. This deficiency can be made up by using in place of plain salt a mixture of 100 parts of salt and 1.7 parts of anhydrous manganous sulfate (or 2.5 parts of manganous sulfate tetrahydrate). One-half of one percent of this mixture in an all-mash diet can be depended on to supply enough salt and enough manganese; but in a laying mash with which grain is to be fed 1 percent should be included.

Vitamin Requirements

Although the importance of several of the vitamins in the feeding of chickens has been recognized by poultry-nutrition workers for at least a dozen years, precise knowledge of the optimum requirements for egg production is still lacking. However, enough is known to enable one to state levels of vitamin intake that are adequate under ordinary conditions. If the eggs are not to be used for hatching, the following quantities of vitamins per pound of feed will usually be adequate: 3,150 International Units of vitamin A, 180 International Units of vitamin B_1, 360 A. O. A. C. chick units[11] of vitamin D, and 680 micrograms (gammas or Cornell chick units[12]) of riboflavin (vitamin G). However, if the eggs are to be used for hatching, the following quantities per pound of feed are recommended: 4,720 International Units of vitamin A, 180 International Units of vitamin B_1, 540 A. O. A. C. chick units of vitamin D, and 1,250 micrograms (gammas or Cornell chick units) of riboflavin (vitamin G). As has been stated already, it is probably always best to feed diets that will permit the chickens to lay eggs of high hatchability; the levels of vitamin intake that are recommended here for producing hatching eggs are therefore to be preferred to those given as being adequate for producing eggs not intended for hatching.

EFFECT OF DIET ON EGGS

As has been shown (p. 791), the diet of chickens affects the composition of the eggs and consequently their market value as human food.

It has been reported that certain feedstuffs, such as onions, rape, turnips, and some fish meals and oils, if fed to chickens in excessive quantities, may have an undesirable effect on the flavor of the resulting eggs. However, if undesirable flavors are found in eggs, it is best to examine a few eggs from each individual chicken in the flock, because it has been found that an occasional bird produces eggs that have an objectionable flavor, regardless of the kind of feed consumed. If only a few chickens are found to be producing off-flavored eggs these should be removed from the flock. However, if the number of such chickens is quite large, the feed may be at fault and an attempt should be made to identify and eliminate the ingredient that is causing the trouble.

No acceptable evidence has been obtained that the feed affects the physical properties, or the so-called "quality," of the white of eggs. On the other hand, the color of the yolk and the ability of eggs to stand up well in cold storage may be readily affected by diet. Very light-colored yolks may be obtained by eliminating green feed from the diet and by replacing the yellow corn with oats, barley, or white corn.

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[11] See footnote 8, p. 796.

[12] See footnote 9, p. 797.

The richer shades of yellow may be obtained through the use of yellow corn and alfalfa-leaf meal; and deep orange-red yolks may be obtained by feeding 0.5 to 2 percent of ground pimiento pepper or chili pepper. Cull peppers are best for this purpose because of their relative cheapness. Cull peppers may be fed also to increase yolk color in the winter when green feed is scarce or not to be had at all.

On some markets a premium is paid for eggs with yolks of light color, but ordinarily uniformity of yolk color is more important than lightness. The best method of obtaining yolks of uniform color is to feed a well-balanced all-mash diet and not permit the chickens to have access to green range. Both a grain mixture and a laying mash may be fed, however, if the ingredients of the grain mixture are so proportioned that it supplies about the same quantity of the coloring matters that affect yolk color as does the mash. The proper proportion of the ingredients of the grain mixture may be determined by trial—the maximum effect of any given diet on yolk color can usually be observed within a week after the diet is first fed.

Cottonseed meal tends to have an undesirable effect on the color of both the yolk and the white. If large quantities are fed the yolks of the resulting eggs may have a brown mottled appearance when laid. And even if small quantities—as little as 5 percent—are fed, the yolks tend to acquire a similar appearance after the eggs have been in cold storage for 6 weeks or longer. Cottonseed meal and weeds of the same botanical family as the cotton plant tend to produce a pink tint in the white. Eggs produced on diets containing cottonseed meal do not stand up well in cold storage; and in addition to the tendency for the yolks to become mottled, there is a tendency for the yolk membranes to become weakened.

The market value of eggs is also affected by the quality of the shells. A deficiency of vitamin D in the diet affects the thickness of the shells and their ability to resist breakage. A deficiency of calcium has the same effect. Also it has been claimed that a deficiency of manganese tends to cause the production of poor shells. Means of insuring against a deficiency of vitamin D, calcium, or manganese have already been discussed.

Egg soilage may also be affected by diet. A diet that tends to cause the droppings to be loose and watery also tends to increase egg soilage. Among the causes of loose droppings are too much salt and too much bran in the diet. Too much salt may be introduced through the use of fish meal of high salt content; such fish meals should not be used. To avoid the effect of too much bran, middlings may be substituted for a part of the bran. At times, the inclusion of 2 or 3 percent of linseed meal in the diet has the desirable effect of making the droppings less watery; more than this quantity should not be used, however, because it tends to have the opposite effect.

NUTRITIVE REQUIREMENTS FOR GROWTH AND FATTENING OF POULTRY

THE UTILIZATION OF FEED FOR GROWTH

As is generally known, the very young animal utilizes feed for growth much more efficiently than does the nearly grown animal. As the

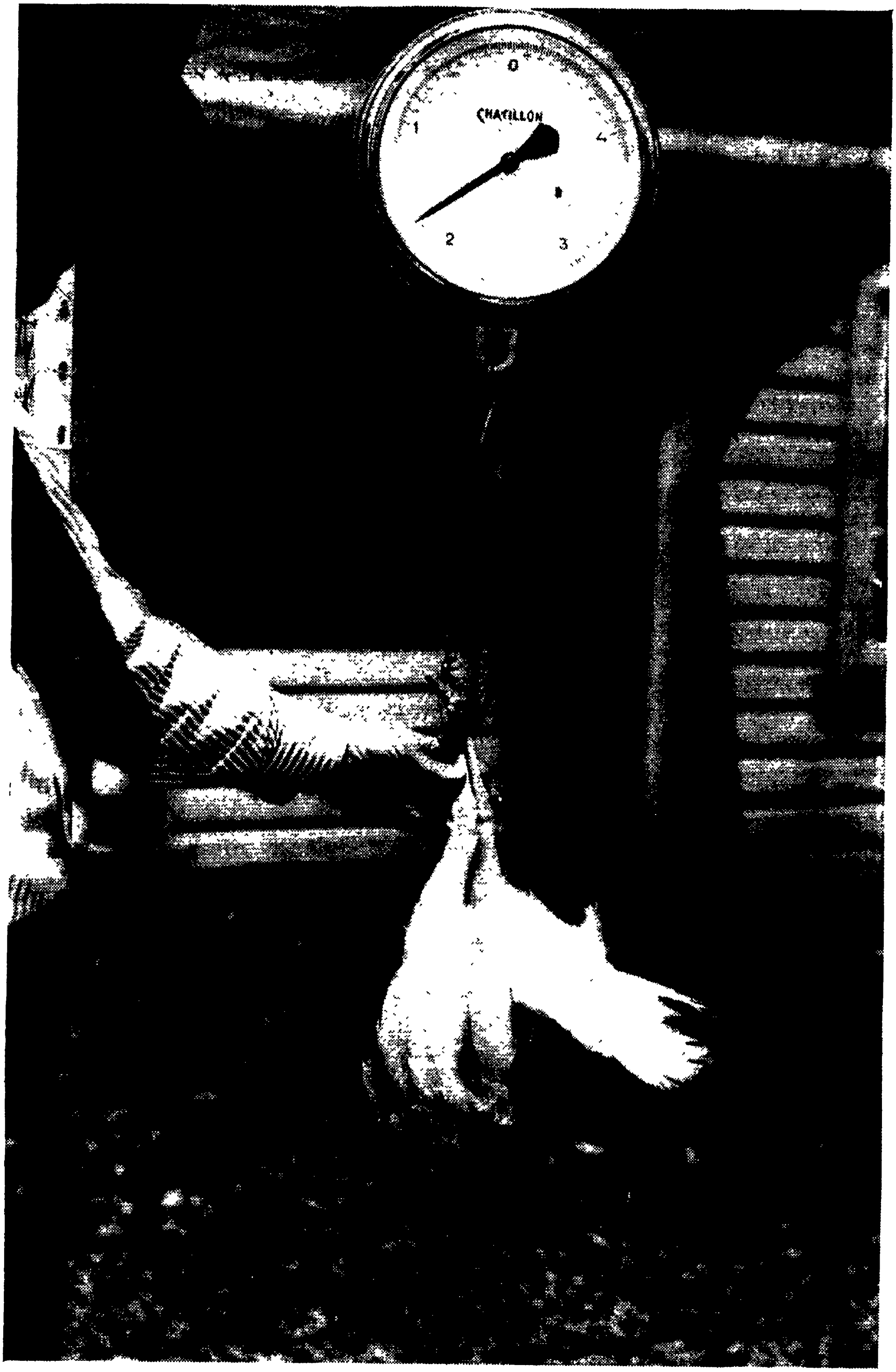

Figure 4.—Regular weighing of birds is necessary in the study of growth.

live weight of an animal increases there is a gradual but very definite decrease in the gain that results from the consumption of a pound of feed. This is due chiefly to the increase in the maintenance requirement, but it is also due in part to the change in the composition of the gain. The general relationship between live weight and feed consumption is illustrated by figure 2 (p. 451). Regular weighing of the birds is necessary in the study of growth. Figure 4 shows a young turkey being weighed in connection with growth studies.

It was formerly believed that animals consume less feed per pound of gain in live weight when they are allowed to eat all they want than when they are fed somewhat less than this quantity. However, Ellis and Zeller (*319*, *320*) have shown that this is not true in the case of swine, and the work of Hammond, Hendricks, and Titus (*468*) clearly indicates that it is not true in the case of chickens. In an experiment conducted by the last-named investigators, seven lots of chickens were fed for a period of 52 weeks all they would eat of seven diets of different protein content, and another seven lots were fed 70 percent as much of the same diets. On each diet the feed was utilized more efficiently by the lot that was fed at the 70-percent level of feed intake. On the diet that contained the least protein (13 percent) the efficiency of the utilization of feed for growth was only about 4 percent greater at the 70-percent level than it was at the full-feed level, but as the percentage of protein in the diets increased the differences in efficiency became more and more pronounced. On the diet of highest protein content (25 percent) the efficiency was about 38 percent greater at the 70-percent level than at the full-feed level.

TABLE 2.—*Effect in male chickens of the heavier breeds of the level of feed intake on the relative efficiency of utilization of feed for growth, the relative maximum live weight attained, the relative quantity of feed required for attaining the maximum live weight, and the relative length of time required to attain maximum live weight on a diet containing about 19.4 percent of crude protein*

Level of feed intake as percent of full feed	Relative average efficiency of utilization of feed for growth	Relative maximum live weight [1] attained	Relative quantity of feed required for attaining maximum live weight [1]	Relative length of time required to attain maximum live weight [1]
	Percent	*Percent*	*Percent*	*Percent*
20	90.7	19.1	21.1	105.1
30	93.3	51.1	54.7	103.6
40	97.2	77.7	79.9	101.9
50	100.0	100.0	100.0	100.0
60	99.1	114.9	116.0	98.1
70	96.8	127.7	131.9	94.9
80	94.8	138.3	145.9	89.9
90	93.1	148.9	159.9	82.0
100	92.6	156.6	169.2	73.2

[1] This refers to the maximum live weight that is eventually attained after a prolonged period of feeding at the levels indicated in the first column.

In order to get additional information about the effect of the level of feed intake on the efficiency of the chicken in utilizing feed for growth, the writer reexamined both published (*1143*) and unpublished data obtained with chickens at the Agricultural Research Center, Beltsville, Md. Some of the results of this reexamination are summarized in table 2. This table contains data only for male chickens that were fed a diet which contained about 19.4 percent of protein. Apparently, the feed was utilized most efficiently for growth when the level of intake was between 50 and 60 percent of full feed. However, other data obtained by the writer indicate that the maximum efficiency is sometimes observed between the 60- and 70-percent levels. In any case, it may be concluded that a full-fed, growing chicken makes a smaller gain per pound of feed than a growing chicken fed at a much lower level of feed intake, if the diet contains between 13 and 25 percent of protein.

In the practical production of chickens for meat it would not be economical to feed growing stock at a level of feed intake that is only 50 to 60 percent of full feed, even though the feed is utilized more efficiently for growth at such a level. The data in table 2 indicate why this is true. According to these data it would require more than twice as much time, with the same brooding and housing facilities, to produce the same weight of live chickens at the 50-percent level of feed intake as it would at the full-feed level. Or, to state it another way, by feeding only 69 percent more feed at the full-feed level of intake one would get nearly 57 percent more live weight, in about 27 percent less time, than would be obtained by feeding at the 50-percent level. Moreover, the chickens that would be produced on this low level of feed intake would have little fat, and hence would have a lower market value per pound than those produced on full feed.

TABLE 3.—*Quantities of feed required to obtain certain selected average live weights with different kinds of poultry*

Average live weight (pounds)	Kind of poultry and quantity of feed required per bird				
	White Leghorn chickens (males and females) [1]	Cross-bred [2] chickens (males)	Rhode Island Red chickens (males)	Turkeys [3] (males)	White Pekin ducks (males and females) [1]
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*
0.5	1.20	1.29	1.12	0.95	0.83
1.0	3.18	2.91	2.53	2.20	2.01
1.5	5.27	4.65	4.05	3.49	3.28
2.0	7.75	6.52	5.69	4.83	4.66
2.5	10.80	8.56	7.49	6.21	6.17
3.0	14.75	10.78	9.46	7.65	7.83
3.5	20.39	13.24	11.66	9.15	9.68
4.0	----------	15.97	14.13	10.70	11.77
4.5	----------	19.07	16.95	12.32	14.17
5.0	----------	22.62	20.25	14.02	16.99

[1] For a group containing approximately the same number of birds of each sex.

[2] The male offspring resulting from mating Barred Plymouth Rock females to Rhode Island Red males.

[3] Several different breeds from parent stock which had been selected for small size.

All breeds of chickens are not equally efficient in their utilization of feed for growth; likewise different kinds of poultry are not equally efficient. According to the few data that are available, both ducks and turkeys are more efficient than the heavier breeds of chickens, which in turn are more efficient than the lighter breeds. Some data on the feed required to obtain certain selected average live weights with different kinds of poultry are given in table 3. Since no two of the diets that were fed in obtaining these data were the same, it is not possible to make exact comparisons of the efficiencies of the different kinds of poultry in utilizing feed for growth. Nevertheless, diets suitable for each kind of poultry were fed, and hence the data indicate in a general way the relative abilities of chickens, turkeys, and ducks to utilize feed for growth.

NUTRITIVE REQUIREMENTS FOR GROWTH

On the nineteenth or twentieth day of incubation the yolk sac is drawn into the body of the embryo and on the twenty-first day a fully formed chick is normally ready to emerge from its shell. Whether or not the embryo develops into a fully formed chick is dependent to a considerable extent on the diet that was consumed by the mother. Likewise the viability of the hatched chick is dependent, at least in part, on the diet of the parent stock. The unabsorbed yolk in the body of the hatched chick is a concentrated reserve supply of nutrients on which the chick may subsist for several days even though it receives no feed. Experience has shown, however, that it is best to supply both water and feed when the chick is about 1 day old, while it still contains some unabsorbed yolk.

If the diet of the newly hatched chick is deficient in proteins, vitamins, minerals, or the energy-producing nutrients, carbohydrates and fats, growth will be retarded and development will be abnormal. If the deficiency is great enough, the chick soon dies. From the standpoint of nutrition, the most critical period in the life of a chick is the first few weeks after hatching (fig. 5). It is during this period that special care should be taken to feed a diet that is fully adequate for the maintenance of health and growth. However, it is good husbandry to provide such a diet throughout the entire growing period.

If the diet is composed of the feedstuffs usually fed to chickens and if it furnishes enough protein of good quality and adequate supplies of the necessary minerals and vitamins, it is not likely to be deficient in carbohydrates or fats; and if it is not too finely or too coarsely ground and contains no harmful ingredients, it is suitable for feeding to growing chicks. Hence, in devising diets for growing chicks special attention should be given to the matter of supplying the proper quantity of protein of good quality and fully adequate but not excessive quantities of minerals and vitamins.

Protein Requirements

Many workers at the State experiment stations in this country have studied the protein requirements of growing chickens and a large amount of information has been accumulated on this important subject. The majority of these workers are in agreement that the optimum percentage of protein in the diet of young growing chickens is not less than 18 or 19 percent, and several of them concur in the belief that the protein content of the diet should be decreased as the chicks become older.

One of the more recent studies of the effect of the percentage of protein in the diet of chickens on their growth and utilization of feed is that of Hammond, Hendricks, and Titus (*468*). Their data have been carefully graduated and the results are given in table 4. The figures in the second column of this table indicate that as the protein content

Figure 5.—From the standpoint of nutrition, the most critical period in the life of a chick is the first few weeks after hatching.

of the diet increases from 13 to 21 percent there is a definite increase in the average efficiency of the utilization of feed for growth, but as the protein content increases from 21 to 25 percent there is a rather sharp decrease in the efficiency. Whether the optimum level of protein intake is exactly 21 percent, as indicated in table 4, or some slightly lower value, cannot be determined from the data, but the optimum level is very probably between 20 and 21 percent. Undoubtedly the optimum level varies with the biological value of the protein,[13] being somewhat less for protein of a high biological value.

TABLE 4.—*Effect in the male chicken of the level of protein intake on the relative efficiency of the utilization of feed for growth, the relative maximum live weight attained, the relative quantity of feed required for attaining the maximum live weight, and the relative length of time required to attain the maximum live weight*

Relative level of protein intake as percent of total feed consumed	Relative average efficiency of the utilization of feed for growth	Relative maximum live weight[1] attained	Relative quantity of feed required for attaining maximum live weight[1]	Relative length of time required to attain maximum live weight[1]
	Percent	*Percent*	*Percent*	*Percent*
13	67.7	97.6	144.1	119.9
14	80.6	97.9	121.3	111.7
15	87.3	98.2	112.5	107.8
16	91.5	98.6	107.7	104.6
17	94.6	98.9	104.6	102.6
18	97.2	99.2	102.1	101.5
19	98.7	99.5	100.7	101.0
20	99.7	99.8	100.1	100.5
21	100.0	100.0	100.0	100.0
22	97.9	100.2	102.3	99.7
23	94.3	100.4	106.4	99.5
24	90.2	100.5	111.4	99.4
25	85.6	100.6	117.5	99.2

[1] This refers to the maximum live weight that is attained when the birds are fully grown.

Apparently the level of protein intake, so long as it is not less than about 13 percent of the total feed consumed, has little effect on the maximum live weight ultimately attained; however, the time required to reach the maximum live weight is greatly increased as the level of protein intake is decreased from 21 to 13 percent. As the level of protein intake is increased from 21 to 25 percent there is only an insignificant decrease in the time required to reach the maximum live weight.

Even though the optimum level of protein intake is, from the physiological standpoint, about 21 percent, from the standpoint of economy it may be only 18 or 19 percent, because the efficiency of feed utilization for growth is only slightly less at these levels than it is at the 21-percent level. In most cases the difference in cost between a diet that contains 21 percent of protein and one that contains only 18 or 19 percent will be an important factor in determining the most economical level of protein intake. In any case, the writer has found that it is a good practice to feed a diet that contains 20 to 21 percent of protein until the chickens are about 12 weeks old and then to gradually decrease the protein content to about 16 or 17 percent by the time the pullets are ready to lay. The pullets may then be placed on a diet that contains about the same quantity of protein, that is, 16 to 17 percent, but which is more suitable for the production of eggs.

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[13] See the article on Protein Requirements of Man, p. 173.

The protein requirement of young growing turkeys (fig. 6), according to the few data available on the subject, is nearly 20 percent greater than that of young growing chickens. The optimum level of protein intake is about 25 percent for the first 12 weeks, but after that it may be reduced gradually to about 17 by the time the turkeys are 24 weeks old, and then to 14 or 15 by the time they are ready for market. After the thirtieth week the turkeys that are being kept as breeding stock may be fed a diet that contains only 13 or 14 percent of protein; but about a month before eggs are to be obtained for hatching, the protein content of the diet should be increased to about 16 or 17 percent and held there until the breeding season is over.

Mineral Requirements

After reviewing the literature on the calcium and phosphorus requirements of farm animals, Mitchell and McClure (*803*) concluded that the young growing chicken's average minimum requirements for these elements are represented by concentrations of about 0.70 to 0.75 percent of calcium and about 0.4 percent of phosphorus in the diet. From the studies of Mussehl and Ackerson (*833*) it may be concluded that the minimum requirement of turkeys for calcium is about the same as that of chickens, or possibly slightly greater.

In the practical feeding of poultry it is desirable to guard against possible deficiencies by feeding somewhat more of all the necessary nutrients than the minimum quantities required. This is true of the several mineral elements, as it is of protein and the vitamins, but, especially in the case of minerals, care should be taken not to supply too much. Although there is little accurate information about the optimum calcium and phosphorus requirements of growing chickens and turkeys, it is possible to state levels of intake that can be depended on to give satisfactory results.

A satisfactory level of phosphorus intake is 0.7 percent of the diet, but many practical diets contain much more than this. Since the utilization of calcium is intimately associated with that of phosphorus, it is desirable to know what the level of calcium intake should be for any given level of phosphorus intake. Apparently the chicken can readily excrete the excess calcium and phosphorus in any ratio from about 1.3:1 (1.3 parts calcium to 1 part phosphorus) to about 2:1 (2 parts calcium to 1 part phosphorus). Also, according to the studies of Ackerson and associates (*9, 10, 11, 12, 13*), the ratio of the retained calcium to the retained phosphorus varies in the young growing chicken from 1.3:1 to nearly 1.7:1, with an average value of about 1.5:1. From this it may be concluded that the ratio of calcium to phosphorus in the diet may vary from 1.3:1 to 2:1. The optimum ratio is probably between 1.5:1 and 2:1, and experience has shown that a ratio of about 1.6:1 is quite satisfactory. Therefore it may be considered a good practice to have the diets of both chickens and turkeys contain not less than 0.7 percent of phosphorus and to adjust the calcium content so that there is about 1.6 times as much calcium as phosphorus.

So far as is known, the salt requirements of growing chickens and turkeys are about the same as those of laying chickens (p. 805), or about 0.5 percent of added salt.

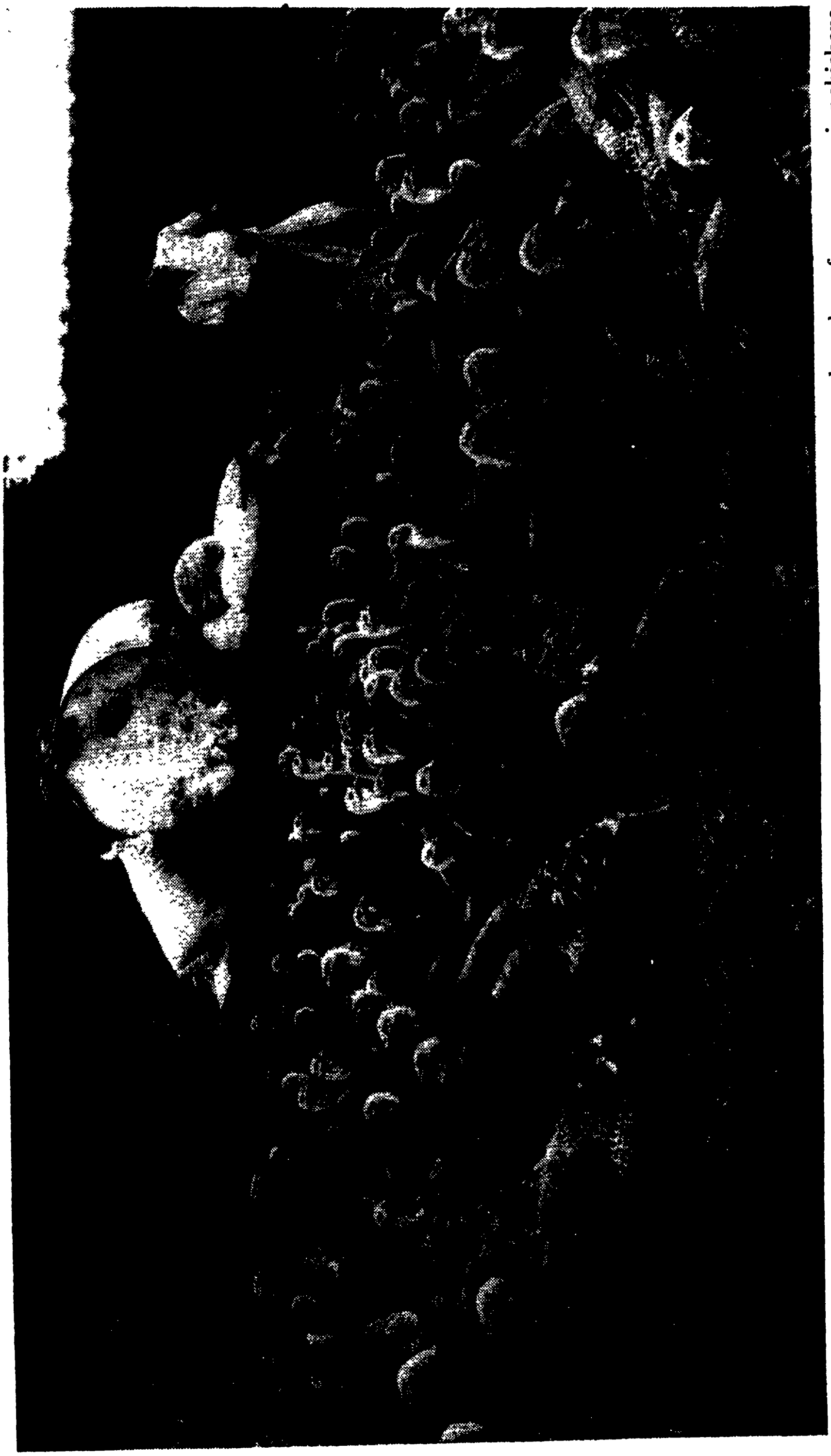

Figure 6.—The protein requirement of young growing turkeys is apparently almost 20 percent greater than that of young growing chickens.

The optimum quantity of manganese in the diet is about 50 parts per million, or 50 milligrams per kilogram (p. 797). Inasmuch as certain types of diets commonly fed to poultry may not contain this much manganese, it is a good practice to guard against a possible deficiency by adding about 30 parts per million. One-half of one percent of a mixture of 100 parts of salt and 1.7 parts of anhydrous manganous sulfate (or 2.5 parts of manganous sulfate tetrahydrate) is sufficient in all-mash diets, but in growing mashes as in laying mashes with which grain is to be fed 1 percent should be included.

There is no acceptable evidence that the usual diets fed to chickens or turkeys are likely to be deficient in any of the mineral elements other than those just discussed.

Vitamin Requirements

During recent years the vitamin A requirement of growing chickens has been carefully studied (*951*, *969*), and it is now possible to state both the approximate minimum requirement and the approximate optimum level of intake. The minimum requirement is about 150 International Units of vitamin A per 100 grams of feed, or about 780 units per pound. The optimum level of intake is at least 320 International Units of vitamin A per 100 grams of feed, or about 1,450 units per pound. Several times this quantity may be fed without harm; and when somewhat more than this quantity can be supplied at no appreciable increase in the cost of the feed, it is recommended that this be done.

The vitamin A requirement of growing turkeys has not been determined as carefully as has that of growing chickens. However, the relatively little information that has been obtained on the vitamin A requirements of turkeys indicates that they require at least 2 to 2½ times as much as chickens. Hence a suitable, practical level of vitamin A intake for growing turkeys would be about 800 International Units of vitamin A per 100 grams of feed, or about 3,630 units per pound.

The minimum vitamin B_1 requirement of growing chickens is about 20 International Units per 100 grams of feed; however, it is well to feed diets that contain about 40 units per 100 grams, or about 180 International Units per pound. So far as is known the vitamin B_1 requirement of growing turkeys is essentially the same as that of growing chickens.

The growing chicken's requirement for vitamin D has been studied more extensively than has its requirement for any of the other vitamins. Most of the workers agree that the minimum requirement is between 15 and 20 A. O. A. C. chick units of vitamin D per 100 grams of feed, but the studies of Couch, Fraps, and Sherwood (*230*) indicate that for certain levels of calcium and phosphorus intake the minimum requirement may be appreciably less. However, the optimum level of vitamin D intake is probably as much as 40 A. O. A. C. chick units per 100 grams of feed, or about 180 A. O. A. C. chick units per pound.

According to Baird and Green (*54*) the growing turkey requires between 60 and 70 A. O. A. C. chick units per 100 grams of feed, which is appreciably more than the growing chicken requires. The optimum level of vitamin D intake for young growing turkeys is probably about 80 A. O. A. C. chick units per 100 grams of feed, or about 360 A. O. A. C. chick units per pound.

It is very probable that the young growing chicken requires vitamin E for normal growth and development but its requirement for this factor has not been determined. Most poultry-nutrition workers agree that good, typical diets for growing chickens contain all the vitamin E that is required and that it is both unnecessary and a waste of money to use such expensive sources of vitamin E as wheat-germ oil to increase the vitamin E content of the diet. In any case, dependable information about the growing chicken's vitamin E requirement is very desirable and should be obtained.

D-riboflavin, or riboflavin, is sometimes referred to as vitamin G. The growing chicken has a relatively high requirement for this vitamin. Most of our knowledge of the vitamin G requirement of growing chickens has resulted from the studies of Norris and associates (*862*) at Cornell University. The proper level of vitamin G intake for young growing chickens appears to be about 370 micrograms (gammas) of riboflavin per 100 grams of feed, or about 1,670 micrograms of riboflavin per pound. Apparently, young growing chickens and turkeys have about the same vitamin G requirement.

Certain fat acids, that is, linoleic, linolenic, and arachidonic acids, have been referred to as vitamin F. Whether or not the growing chicken requires these fat acids is not known. In addition to the vitamins which have been discussed here, the growing chicken requires the (1) chick antidermatosis factor, (2) vitamin K, (3) the anti-gizzard-erosion factor, and probably (4) vitamin B_4. There is, however, little information about the quantitative requirements of the growing chicken for the last three of these four factors. According to the available information, the feed of growing chickens should contain about 0.9 modified Jukes-Lepkovsky unit[14] of the chick antidermatosis factor per pound.

NUTRITIVE REQUIREMENTS OF CHICKENS BEING FINISHED (FATTENED) FOR MARKET

The nutritive requirements of chickens that are being finished, or fattened, for market depends on their age. Broilers should be fed essentially the same kind of diets that are usually fed to growing chickens, but roasters, capons, and fowls are best finished on diets that contain considerably less protein.

Ordinarily no advantage is gained by feeding broilers a special finishing diet; however, fish oils and fish meals are best omitted from the diets of growing chickens about 2 weeks before they are to be marketed, or the flesh of the chickens may have a fishy taste. Sometimes, however, a special diet is fed to broilers for several days before they are killed. This is done primarily for the purpose of improving the market quality and hence the value of the carcass. Finishing diets for broilers should contain about 18 percent of protein (air-dry basis), and they should possess all the nutritive properties of a growing diet but need not contain any special sources of vitamin D. However, when the finishing diet contains no source of vitamin D, it is necessary for the dietary calcium-phosphorus ratio to be increased to about 2.3:1 to prevent the development of brittle wing and leg bones.

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[14] This unit for the measurement of the quantity of chick antidermatosis factor in feeding stuffs is designated as the Jukes-Lepkovsky unit because these two workers at the University of California were the first to devise a method of assaying foodstuffs for this factor.

Diets for finishing roasters, capons, and fowls need not contain more than 14 to 15 percent of protein. The quantities of the several vitamins may be reduced to about one-half of those recommended for growing chickens. It is desirable that the calcium and phosphorus content of diets for finishing these classes of market chickens be about 1 and 0.5 percent, respectively, or in the ratio of about 2 to 1.

Finishing diets should contain between 6 and 10 percent of fat (air-dry basis). Most finishing diets for market poultry do not contain this much fat, so it is a good practice to add some. Corn oil has been found to be quite well suited for this purpose, although if the finishing period is prolonged it tends to make the skin of the birds yellow, which is not desirable on some markets. Other oils, such as red palm oil, rapeseed oil, and peanut oil may be used. The quantity of oil to add to a finishing diet depends on its fat content; ordinarily the proper amount is between 2.5 and 6 percent.

SUMMARY OF THE NUTRITIVE REQUIREMENTS OF CHICKENS AND TURKEYS

The nutritive requirements of chickens and turkeys are summarized in table 5. In using this table reference should be made to the text. It will also be desirable to refer to the article that deals with the practices and economics of feeding poultry (p. 819).

TABLE 5.—*Requirements of different classes of chickens and turkeys for protein, minerals and vitamins for satisfactory growth and development under various conditions observed in practice*

CHICKENS

Class	Protein [1] as proportion of total feed	Phosphorus as proportion of total feed	Calcium as proportion of total feed	Manganese in total feed	Vitamin A per pound of total feed [2]	Vitamin B per pound of total feed	Vitamin D per pound of total feed	Vitamin G (riboflavin) per pound of total feed
	Percent	*Percent*	*Percent*	*Parts per million*	*International Units*	*International Units*	*A. O. A. C. chick units*	*Gammas (or micrograms)*
Growing chicks	21	0.7	1.1	50	1,450	180	180	1,670
Laying stock	16	1.0	2.4	50	3,150	180	360	680
Breeding stock	16	1.0	2.4	50	4,720	180	540	1,250

TURKEYS

Class	Protein [1] as proportion of total feed	Phosphorus as proportion of total feed	Calcium as proportion of total feed	Manganese in total feed	Vitamin A per pound of total feed [2]	Vitamin B per pound of total feed	Vitamin D per pound of total feed	Vitamin G (riboflavin) per pound of total feed
Growing poults	25	1.0	1.6	50	3,630	180	360	1,670
Breeding stock	16	1.0	2.4	50	4,720	180	540	1,250

[1] The protein must be of reasonably good quality; and it is desirable that not less than 20 percent be derived from animal sources.

[2] If the feed is to be stored for more than a month before it is fed, not less than 70 percent of the vitamin A should be derived from plant sources.

PRACTICAL FEEDING OF POULTRY

by Harry W Titus[1]

IN THIS ARTICLE the four principal systems of poultry feeding—all-mash, mash-grain, pellet, and grain-milk—are described, and numerous combinations of feedstuffs are given, with recommendations for quantities, to fit various farm conditions. There is a discussion of nutritional disturbances from the standpoint of cause and cure, and of the relation of certain management practices to good nutrition in poultry. Tables at the end of the article give analyses of most of the common feedstuffs available to poultrymen.

WHEN POULTRY is kept primarily as a source of income, as it is in most instances, it is desirable to have as much knowledge as possible of the factors that influence the cost of production. The various studies that have been made of the economics of poultry keeping indicate that feed accounts for 50 to 60 percent of the total cost of producing poultry meat and eggs. The prices of feeding stuffs vary from year to year and even from season to season; and so it sometimes happens that a feeding stuff which it is economical to use at one time may not be economical at some other time. Thus, it is readily apparent that careful thought should be given to the nutritive value of the feeding stuffs used, their cost, their mutual replaceability, and their suitability.

In general, if a profit is to be made, all the necessary nutritive elements must be supplied in adequate quantities and as cheaply as possible. Frequently the cost of the feed may be reduced appreciably by the substitution of one feeding stuff for another; but there are times when a certain feeding stuff can be replaced only by a combination of two or more other feeding stuffs. Whenever substitutions are made, the resulting diet should be carefully checked to find out whether or not it contains enough of all the necessary nutrients, especially protein, minerals, and vitamins. The tables in the appendix will aid poultrymen materially in making substitutions.

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SUPPLYING THE NUTRITIVE ELEMENTS

In selecting the ingredients to be used in compounding any diet, consideration should be given to their palatability. Of two feeding stuffs of equal cost and apparently equal nutritive value, the more palatable should be chosen. Palatability is of great importance because any marked reduction in feed consumption usually results in slower growth or a reduced egg production.

The so-called texture of a feed mixture is also of great importance. The fineness to which the several ingredients are ground is one factor influencing both texture and palatability. Feed mixtures that are too finely ground or that would form a sticky mass in the mouth and be swallowed with difficulty should not be used. A granular, loose-textured mixture of feeding stuffs is nearly always palatable and therefore to be preferred. Of course, the feed particles in a diet intended for very young chicks should be smaller than those in a diet intended for older chickens, but in no case should they be of a flourlike fineness.

As a result of our knowledge of the nutritive properties of feeding stuffs it is possible to choose the ingredients of a diet on the basis of their ability to serve as sources of one or more specific nutrients. For example, the cereal grains are used as sources of readily digestible carbohydrates, but generally yellow corn is preferred to all the others because it is a better source of vitamin A. Dried skim milk is used because it is a relatively good source of vitamin G (riboflavin) and of protein of excellent quality. Fish meal and meat scrap are also good sources of protein of very good quality and in addition supply relatively large quantities of calcium and phosphorus. Bran and middlings are sources of several of the vitamins and vitaminlike factors and tend to improve the texture of a mixture of feeding stuffs. Alfalfa meal and alfalfa-leaf meal are good practical sources of vitamins A and G and some others as well. Cod-liver oil and other fish oils are used as sources of vitamin D and sometimes of vitamin A. Linseed meal is a source of certain so-called essential fat acids and, if the proper quantity is used, tends to impart desirable physical properties to the feed masses in the intestines and to the excreted fecal masses so that they are less likely to soil the eggs.

THE ENERGY-PRODUCING NUTRIENTS

Although all the usual ingredients of typical diets for poultry, except salt, limestone, and oystershell, supply some energy, the chief sources of energy are the cereal grains and the grain sorghums. The latter, however, are not used so extensively in the feeding of poultry as are the former.

A fairly large number of experiments have been conducted to determine the relative value of the different grains when they are fed at the same level in otherwise similar diets. The results show little difference in the gains of growing chicks regardless of which grain is used, provided the diets contain all the necessary protein, vitamins, and minerals. Oatmeal is somewhat more efficient in producing gains in live weight than corn, wheat, barley, or whole oats, but usually it is also more expensive.

For laying hens corn appears to be slightly superior and oats slightly inferior to barley and wheat. For chickens being finished for market, there seems to be little or no difference between diets that contain equal quantities of corn, wheat, oats, or barley. There is some evidence, however, that the flesh of chickens finished on diets containing chiefly corn or barley is superior to that of those finished on diets containing chiefly wheat or oats. White corn and oats are widely used in finishing diets because they do not tend to color the skin yellow as does yellow corn.

Notwithstanding the statements just made, the relative nutritive values of the cereal grains and grain sorghums are roughly indicated by their content of total digestible nutrients. Selected data on the digestibility in the chicken of a small number of feeding stuffs are given in table 8 (p. 842). As has been pointed out, however, many feeding stuffs are included in the diet because they possess certain specific properties, so it is clear that the content of total digestible nutrients should not be used as the sole criterion in deciding whether or not to make a substitution of one feeding stuff for another. For example, if a diet that contains yellow corn supplies only slightly more vitamin A than is needed, it would be inadvisable to substitute oats, wheat, or barley for the yellow corn, even though they may be considerably cheaper as sources of digestible nutrients. The substitution should be made only if sufficient vitamin A is supplied through the use of some other suitable feeding stuff, such as alfalfa-leaf meal, and the advisability of the change would be determined by the cost of the resulting diet as compared with the cost of the original diet.

THE PROTEIN

There are many different proteins, but all of them are composed of a relatively small number of comparatively simple compounds known as amino acids. The chicken is able to make in its own body some, but not all, of these amino acids, and unless most of those which it cannot make are present in the feed normal nutrition is impossible. A protein is said to be of good quality if it contains a sufficient quantity of the amino acids the animal is unable to make but which it requires for normal growth and reproduction. In the practical feeding of animals two classes of proteins are commonly referred to—those derived from plants and those derived from animals, or plant proteins and animal proteins. In general the animal proteins are superior in quality to the plant proteins.

Owing to the variability of the several protein supplements used in compounding diets for poultry, it is not possible to state their relative values for growth or reproduction in precise terms. Nevertheless, it is possible to indicate their relative values in a qualitative way by using a system of numbers in which 1 represents the highest value, 2 the next highest, 3 the next, and so on. According to studies of Mussehl and Ackerson (*832*)[2] and data obtained at various times by the writer and his associates, the more common protein supplements may be rated as follows:

Dried skim milk	1	Soybean meal	2
Dried buttermilk	1	Peanut meal	2–3
Fish meal (best grades)	1	Cottonseed meal	3
Meat scrap	2	Linseed meal	4
Fish meal (poorer grades)	2	Corn-gluten meal	4
Hempseed meal	2	Soybeans	4

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[2] Italic numbers in parentheses refer to Literature Cited, p. 1075.

According to data obtained by Wilgus, Norris, and Heuser (*1221*), the best grades of fish meal are whitefish meal (either vacuum or steam dried) and the domestic sardine meal. Flame-dried menhaden fish meal usually has been the poorest of those used in feeding chickens, but since 1935 there have been marked improvements in it. The domestic fish meals are usually greatly superior to the imported.

Wilgus, Norris, and Heuser (*1221*) also obtained data on the relative "protein efficiency" of several kinds of meat scrap that differed from one another in their protein content. Apparently the best was the one that contained about 55 percent of protein, although it apparently was but little better than the one that contained 60 percent. However, the protein content of meat scrap cannot be used as a reliable indicator of the protein efficiency of this product because the proportion of the different materials that are used in its manufacture varies according to the demand for them for other purposes. During the last year or two, as a result of a change in the demand for some of these materials, particularly those used in the manufacture of glue and gelatine, meat scrap that contains the higher percentages of protein has tended to be of better quality than it was when Wilgus, Norris, and Heuser obtained their data.

It is a well-established fact that some proteins supplement each other—that is, give better results when fed together than when fed alone. The experiments of Ackerson, Blish, and Mussehl (*12*) indicate that one-third of a mixture of fish meal and meat meal may be replaced by soybean meal without any decrease in the relative value of the mixture as a protein supplement. Unpublished data obtained at the Department's Southwest Poultry Experiment Station, Glendale, Ariz., have shown that a mixture of equal parts of meat scrap and hempseed meal has about the same value as meat scrap.

It is not possible to give hard and fast rules for selecting protein supplements, because they vary in their nutritive value. However, in order to insure that the protein in the diet is of suitable quality, it is a good practice to derive between 20 and 40 percent of it from feeding stuffs of animal origin, such as dried skim milk, dried buttermilk, fish meal, and meat scrap.

THE MINERALS

In order to supply all the mineral elements that the chicken requires, it usually is necessary to include in the diet some calcium carbonate, salt, and manganous sulfate. Occasionally it is desirable to add some steamed bonemeal as a source of phosphorus.

The best sources of calcium carbonate are high-calcium limestone and oystershell. Limestones that contain not less than 39 percent of calcium are to be preferred to all other grades, but those that contain between 32 and 39 percent may be used. Oystershell that has been obtained in the shucking of oysters is ordinarily better than the so-called oystershell that is obtained from shell deposits, because the former nearly always has a higher calcium content. Good grades of properly cleaned oystershell contain approximately 38 percent of calcium. If a given lot of oystershell contains appreciably less than this percentage of calcium, it is an indication that it may have been obtained from shell deposits.

Any good grade of common salt may be used. It is desirable, however, that it be finely granular and free flowing. If lumps are present, the salt should be passed through a fine-meshed sieve in order to insure that there will be no lumps in the feed. Iodized salt may be used if desired.

Anhydrous manganous sulfate is the form in which manganese is most commonly added to feed mixtures for poultry, and it is also one of the most suitable forms. If it is not readily obtainable, manganous sulfate tetrahydrate may be used, but this supplies only about two-thirds as much manganese as the anhydrous product so that almost half again as much must be used.

When the diet contains little or none of the animal protein supplements, it is desirable and sometimes necessary to add some form of calcium phosphate. The most suitable form is steamed bonemeal. Raw rock phosphate should not be used unless it is definitely known that it contains no fluorine.

THE VITAMINS

Vitamin A

In formulating diets for chickens, it is necessary to give special attention to the matter of supplying vitamin A. There are two reasons for this: (1) The chicken's vitamin A requirements for growth and reproduction are relatively high, and (2) vitamin A is not very stable in feed mixtures.

Fraps and Kemmerer (*388*) found that under the climatic conditions at College Station, Tex., practically all the vitamin A, added to feed mixtures in the form of cod-liver oil, other fish oils, or cod-liver-oil concentrates, was lost after about 4 weeks of storage. They also found that the addition of the antioxidant, hydroquinone, delayed the destruction by only a week or two. Although climatic conditions are probably somewhat more conducive to the destruction of vitamin A in mixed feeds at College Station, Tex., than throughout the rest of the country on the average, the fact remains that under ordinary conditions during the warmer months of the year the destruction of vitamin A, when added in the form of fish-liver oils, fish oils, or concentrates of these oils, may be virtually complete after 4 months.

The richest source of vitamin A used in feed mixtures for poultry is so-called fortified cod-liver oil, which is cod-liver oil to which vitamin A and vitamin D concentrates from other fish oils or fish-liver oils have been added. It contains, on an average, somewhat more than 1,300,000 International Units of vitamin A per pound. Straight cod-liver oil, which averages a little more than 340,000 units per pound, is the next richest source. Although some lots of dehydrated alfalfa-leaf meal may contain over 200,000 units of vitamin A activity per pound, the average for alfalfa-leaf meals in general is about 60,000. Sardine oil has a vitamin A activity of about 45,000 units per pound. Other feeding stuffs that may be used as important sources of vitamin A activity are, in decreasing order of potency: Corn-gluten meal made from yellow corn, garden peas, yellow corn, field peas, wheat-germ meal, and cowpeas. Under the various conditions under which poultry are kept, the most practical source of vitaimin A activity is high-grade alfalfa-leaf meal; yellow corn is also a good practical source but its potency is much less than that of alfalfa-leaf meal. Fresh green grass is an excellent source, having on an average about 107,000 International Units of vitamin A per pound, but it is not always available. The vitamin A content of a number of feeding stuffs is given in table 9 (p. 842).

The situation in regard to the precursors of vitamin A—those substances in the feed which most animals are able to convert into vitamin A in their bodies—is somewhat different from that of vitamin A itself. For example, carotene, one of these precursors, is relatively more stable than vitamin A, even when it is extracted from plant materials and then added to the feed in the form of an oil solution. Moreover, the precursors of vitamin A are much more stable in the feeding stuffs in which they occur than they are in oil solutions.

Although corn may lose about 50 percent of its vitamin A activity and dehydrated alfalfa-leaf meal as much as 85 percent after 9 or 10 months of storage, some samples of these feeding stuffs may retain some vitamin A activity after 18 months or more of storage. The important point, however, is that all feeding stuffs tend to lose vitamin A activity with age. Furthermore, the rate of loss is increased if they are ground and mixed with other feeding stuffs to make a feed mixture.

Vitamin B_1

Vitamin B_1 appears to be rather stable in feeding stuffs and in feed mixtures. Inasmuch as the minimum vitamin B_1 requirement of the chicken is only about 90 International Units per pound of feed, and most if not all grains, seeds, and their byproducts contain at least 200 International Units per pound, there is little likelihood that typical diets of poultry will be deficient in this vitamin.

Vitamin D

Under the usual conditions of brooding, the chicks may not receive enough vitamin D unless some is added to their diet. Likewise, laying stock may not get enough of this vitamin if they do not get plenty of sunshine. Accordingly, it is necessary to add some vitamin D to the diet of laying stock kept in confinement. Even if the chickens are given access to range, they may not get enough sunshine during the winter months to meet their vitamin D requirements. In general, it is a good practice to add some vitamin D to all diets fed to chickens unless the chickens have access to plenty of sunshine—and this rarely happens except during the late spring, summer, and early fall. It is especially desirable to add some vitamin D to the diet of growing chicks during their first 8 weeks no matter what season of the year they are brooded and whether or not they have access to sunshine.

Vitamin D is much more stable in feed mixtures than is vitamin A; feed mixtures may be kept for 6 months or longer without any serious loss of vitamin D occurring. Most feeding stuffs contain little or none of this important vitamin. As in the case of vitamin A, the richest source of vitamin D used in feed mixtures for poultry is fortified cod-liver oil. It contains on an average somewhat more than 180,000 A. O. A. C. chick units[3] per pound. Straight cod-liver oil averages about 45,000 units per pound and cannot legally be sold as such if it contains less than 85 units per gram, which is about 38,590 units per pound. Sardine oil has about the same vitamin D potency as straight cod-liver oil and is widely used in feed mixtures for poultry.

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[3] The standard unit of the A. O. A. C.—the Association of Official Agricultural Chemists. See footnote 9, p. 797.

Vitamin E

So far as is known, vitamin E is quite stable under ordinary conditions but it is quickly and almost completely destroyed by contact with rancid fats. For this reason, it is inadvisable to use feeding stuffs or feed mixtures that show any indication of being rancid. There are few truly quantitative data on the vitamin E content of feeding stuffs; however, this vitamin is widely distributed in nature. Green leaves and the germs of seeds are the best of the known sources; it is also found in some fresh fats and oils. The approximately relative vitamin E content of about a score of feeding stuffs is given in table 9 (p. 842).

Vitamin G (Riboflavin)

Vitamin G (riboflavin) is also quite stable under the usual conditions of feed storage. The richest sources are liver and other glandular tissues, yeast, dried whey, and dried skim milk. Alfalfa, if properly harvested and cured, is a very good source and, in general, alfalfa-leaf meals contain more than straight alfalfa meals. Fish meals, meat scrap, and wheat-germ meal are fair sources. The cereal grains contain relatively very little. The most practical sources of vitamin G are alfalfa-leaf meal, dried skim milk, dried buttermilk, and dried whey. Alfalfa-leaf meal is a particularly desirable source of this vitamin because it also is a very good source of vitamins A, E, and K, and a fair source of vitamin B_1, the chick antidermatosis factor, and the anti-gizzard-erosion factor.

Vitamin K

Vitamin K has been found in such diverse materials as hog-liver fat, hempseed meal, tomatoes, kale, and dried alfalfa. As yet, its occurrence has not been cataloged for a very large number of feeding stuffs.

Anti-Gizzard-Erosion and Chick Antidermatosis Factors

The anti-gizzard-erosion factor has been found in a number of materials, among which are wheat bran, alfalfa products, lung tissues, kale, pork liver and kidney, wheat middlings, and oats.

The chick antidermatosis factor is present in grain, grain products, and various other feeding stuffs. Three of the richest sources are dried yeast, liver meal, and cane molasses. Other very good sources, in the approximate order of their relative content, are peanut meal, dried whey, dried buttermilk, dehydrated alfalfa-leaf meal, dried skim milk, alfalfa meal, wheat bran, rice bran, and soybean meal.

WATER AND GRIT

Water is an essential constituent of all animal tissues and is absolutely essential for all life processes, yet because it is so commonplace its importance is frequently overlooked. A constant supply of fresh, clean water should be kept before poultry all the time. Although the water requirements are greater during hot weather than during cold, there is a greater likelihood of poultry getting too little water during periods of low temperature than at other times. This is because the birds are unable to break any ice that may form on the surface of the water and because of the chilling effect of ice-cold water. For these reasons, simple water-warming devices are usually a good investment.

Although grit is not absolutely essential, it permits chickens to make more efficient use of whole grains and of coarse, fibrous feeding stuffs. Apparently, grit also tends to prevent gizzard erosion in chicks when finely ground feed that contains little fiber is fed. Coarsely crushed oystershell and limestone may serve as grit but their use is not recommended because of the danger of the chickens consuming too much calcium in their effort to get enough grinding material. Therefore, it is desirable to feed all the required calcium in the feed and not permit the chickens to have access to grit that contains calcium. In choosing a grit, care should be taken to select one that is insoluble and nonfriable—that is, cannot be crumbled. Ordinarily, the best materials for use as grit are river gravel and native pebbles; granite, feldspar, and quartz may also be used.

TONICS, MINERAL MIXTURES, AND MISCELLANEOUS MATERIALS

Much money is spent unnecessarily by poultrymen each year for tonics, conditioners, "egg-makers," so-called complete mineral mixtures, and other similar preparations. The best way to have healthy chickens is to feed them a well-balanced diet, keep them free of lice and mites, and keep their houses clean and sanitary. Tonics, conditioners, and egg-makers are of little or no value and merely serve to increase the total cost of producing poultry products. It is not possible to prepare a complete mineral mixture suitable for use in all diets, and the use of such mixtures is not recommended.

VICES AND NUTRITIONAL DISTURBANCES

Although there is some evidence that the three common vices, feather picking, cannibalism, and egg eating, are in part the result of dietary deficiencies, overcrowding is undoubtedly also important among the causes. Feather picking is usually the first of these vices to appear when birds are overcrowded. The exact nature of the nutritional deficiency involved is not known, but it has been found that feather picking is less likely to occur if the diet contains about 20 percent of barley or oats. Trimming back the beak is an effective means of curbing this vice.

"Cannibalism" is a term used by some poultrymen in referring to the habit sometimes developed by chickens of picking one another's toes, combs, vents, feathers, and other parts of the body. Used in this sense, the term also includes feather picking; it is, however, more common to restrict its use to those cases where blood is drawn. Cannibalism is of most frequent occurrence in overcrowded flocks, but it may be due to some as yet unknown deficiency of the diet because the feeding of oats and barley appears to be of some value in prevention. As in the case of feather picking, trimming back the upper beak is an effective curb, but the use of ruby-colored window panes and ruby-colored electric lamps in the poultry house is often a simpler and cheaper means of preventing cannibalism.

Egg eating is also likely to develop as a result of overcrowding; however, the tendency to eat eggs is markedly stimulated by a deficiency of calcium in the diet. It has been observed also that this vice is likely to develop when the chickens do not get enough vitamin D. Other dietary deficiencies also may be contributing causes.

In general, properly fed chickens grow well, lay well, and are healthy. If growth is slow, egg production poor, or mortality heavy, the cause may be an improperly balanced diet that supplies either too little or too much of certain nutrients. It is important, therefore, that the poultryman be able to recognize the symptoms of nutritional deficiency and excesses. Unfortunately, many nutritional deficiencies produce the same general symptoms and it is not always possible to recognize the cause from the symptoms. However, there are a few deficiencies that produce more or less characteristic symptoms and these will be discussed briefly.

A condition known as nutritional roup, which is sometimes mistaken by the layman for contagious catarrhal roup, is caused by a deficiency of vitamin A. It may appear in chickens of any age. The symptoms are a cessation of growth in young chickens, lameness or a staggering gait, discharge from the nostrils, swelling beneath the eyes, and discharge from the eyes; in severe cases blindness and, finally, death result. Examination after death shows swollen follicles in the esophagus, pale kidneys, and frequently white accumulations of urates in the kidneys and ureters.

The symptoms of a deficiency of vitamin B_1 are seldom observed under practical conditions, but they may be produced rather easily in the laboratory. These symptoms are a loss of appetite, emaciation, general weakness and inability to stand, and spasmodic movements of the head and limbs.

A deficiency of vitamin D in the diet of growing chickens produces rickets; but rickets may also be caused by a marked deficiency of either calcium or phosphorus or by a marked imbalance of these elements in the diet. The symptoms are poor growth, lameness accompanied by a stiff-legged gait, thickened leg bones and hock joints, and beading at the ends of the ribs. Spinal curvature and crooked breast bones may also be observed. In mature birds the symptoms of a deficiency of vitamin D are not so obvious, but a careful examination will show that the breast bones have become less rigid. The first symptom of a deficiency of vitamin D in the diet of laying stock is a thinning of the shells of the eggs. A marked deficiency causes a decrease in both egg production and hatchability.

There are no easily recognized external symptoms of vitamin E deficiency in the chicken. Recently, it has been claimed that a deficiency of vitamin E causes chickens to become more susceptible to range paralysis but adequate proof that this is so is definitely lacking. It is possible to prepare in the laboratory diets so deficient in vitamin E that they will seriously affect hatchability; however, in actual practice poor hatchability is much more likely to be the result of other deficiencies than it is of a deficiency of vitamin E.

The chief symptoms of a deficiency of vitamin G are a retardation of the growth of chicks and a decrease in the hatchability of eggs. In growing chicks, a marked deficiency of vitamin G causes a twisted or

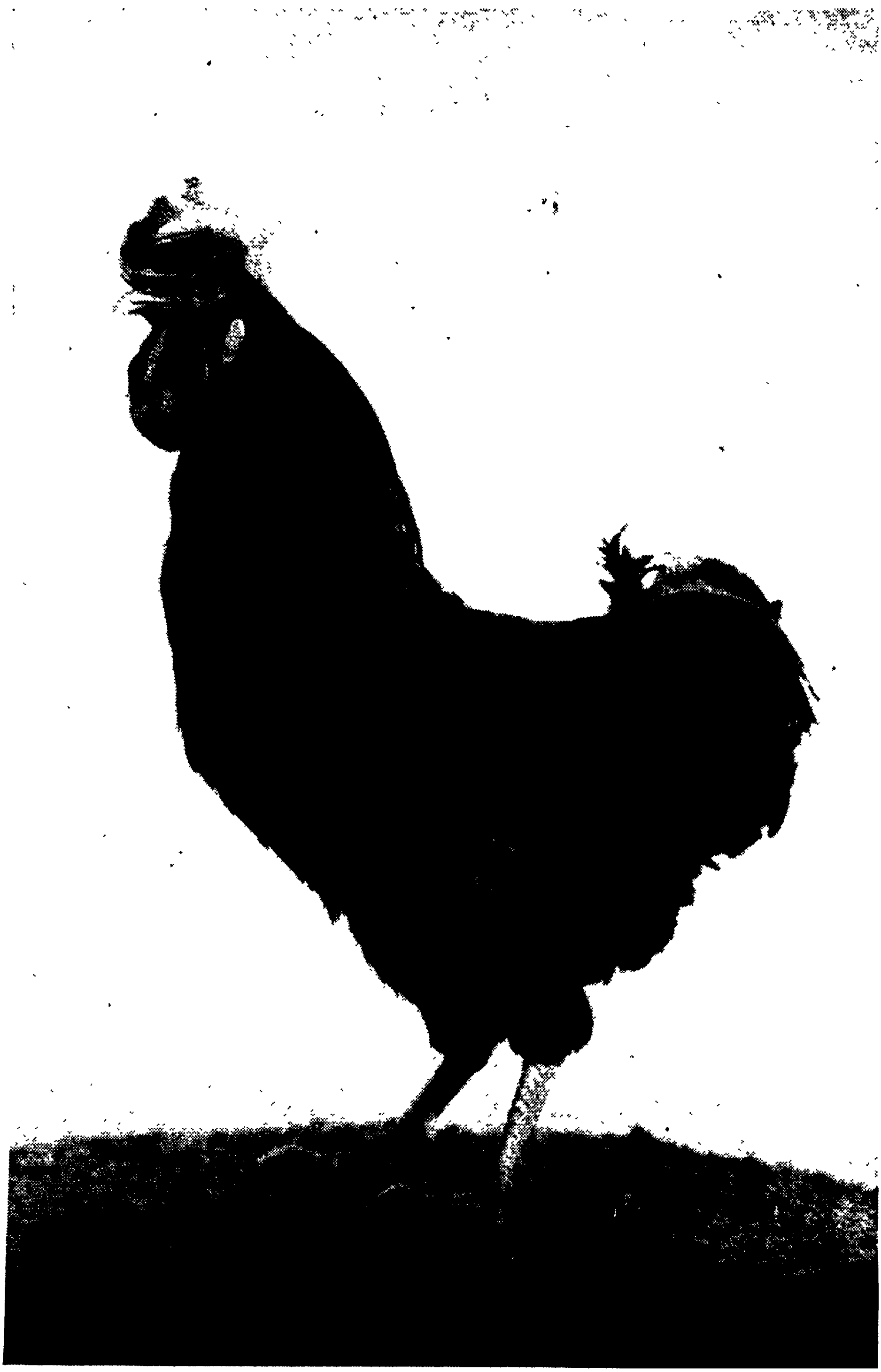

Figure 1.—This rooster lived more than 4 years without a gizzard, thus proving that the gizzard is not an essential organ.

flexed condition of the toes that is referred to as "curled toe" paralysis.

The symptoms of a deficiency of vitamin K have been produced in the laboratory but they are seldom if ever observed under practical conditions. The symptoms, which are easily recognized, are the occurrence of hemorrhages under the skin and throughout the various tissues of the body, and laboratory tests show a marked increase in the clotting time of the blood.

There are no external symptoms of the condition known as gizzard erosion. This condition can be diagnosed only after the bird dies or is killed. (It has been proved, incidentally, that the gizzard is not an essential organ in the chicken. Figure 1 shows a rooster that lived more than 4 years after surgical removal of the gizzard.) There are several types of erosion; in one type there are a number of threadlike, shallow fissures in the gizzard lining; in another there are small holes in the linings; and in still another type, there are small ulcers on the muscular wall at the site of the holes in the lining.

The symptoms of a deficiency of the chick antidermatosis factor in the diet of growing chicks are sores and incrustations at the corners of the eyes and mouth, on the bottoms of the feet, and on the joints of the toes. Also, the feathering is rough and there is a failure of growth.

Perosis (slipped tendons or hock disease) is caused by a deficiency of manganese in the diet. The gross symptoms are an enlargement of the hock joints, bending and rotational twisting of the leg bones, and, in advanced cases, a slipping of the tendons from their normal positions.

At times laying chickens may consume too much calcium and when the excess is great enough the hatchability of the eggs may be appreciably decreased. The consumption of too much oystershell or limestone grit may also cause a slight diarrhea. The obvious remedy is to control the calcium intake by not giving the chickens grit that contains calcium and by using feed mixtures that supply just enough calcium for high egg production.

Another cause of diarrhea is too much salt, which may be introduced into the diet by a mistake in weighing it out or by the inclusion of a fish meal of abnormally high salt content. The diarrhea may be slight or quite pronounced, depending on the quantity of salt consumed. Diarrhea may be caused also by feeding too much bran or too much milk. When egg soilage is excessive as a result of too moist or watery droppings, the various possible causes should be investigated, because even though the health of the birds may not be noticeably affected the market value of their eggs is decreased.

It has been claimed that a high protein intake produces gout in chickens, but there is no good evidence that this is so. At any rate too much protein is to be avoided because it tends to reduce the rate of growth and, if the excess is great enough, it may be a cause of damage to the kidneys.

SYSTEMS OF FEEDING

Nearly every poultryman has his own system of feeding, but most of the various systems may be classified as one of the following or as a modification of one of them: (1) All-mash, (2) mash-grain, (3) pellet, and (4) grain-milk. It cannot be said that one system is better than another under all conditions, but it is true that under certain conditions one system may be superior to the others. In any case, it should be pointed out with as much emphasis as possible that it is far more important to supply poultry with adequate quantities of all the necessary nutrients than it is to follow any given system. Any system that insures adequate supplies of all the necessary nutrients is almost certain to be successful from the standpoint of nutrition. However, any system that ignores the principles of sanitation and economics may fail, no matter how well the poultry may be nourished.

THE ALL-MASH SYSTEM

The all-mash system of feeding derives its name from the fact that all the feeding stuffs used are suitably ground and mixed together to form a mash. In some cases, oystershell or limestone grit is fed in separate hoppers as a supplementary source of calcium; but it is generally best to use an all-mash diet in which all the necessary calcium is included in the form of finely ground oystershell or limestone.

In one simple modification of the all-mash system a part of the mash is moistened and fed as a crumbly wet mash in an effort to increase—or sometimes to maintain—feed consumption. Another modification is to omit dried milk from the all-mash mixture and to feed an equivalent quantity (roughly 10 times as much by weight) of liquid skim milk or liquid buttermilk. When there is a sufficient supply of liquid skim milk or buttermilk, some of the other protein supplements may be omitted from the all-mash mixture and the birds given all the liquid milk they will drink.

It is generally accepted that the all-mash system of feeding is best for the first 4 to 6 weeks. Furthermore, it has been demonstrated repeatedly that this system is suitable for the entire period of growth. Nevertheless, many poultrymen prefer to begin feeding cracked grain some time between the fourth and eighth weeks, that is, to change to the mash-grain system. This, of course, is not necessary and perhaps is undesirable if the all-mash system is to be used after the pullets come into production, but it is the proper thing to do if the mash-grain system is to be used.

One of the chief advantages of the all-mash system in the feeding of laying stock is that it permits the poultryman to control the color of the yolks of the eggs produced. This is of considerable importance because on some markets a premium is paid for eggs with light-colored yolks. Another point is that this system tends to insure a greater uniformity of yolk color, which also is of great importance from the standpoint of the market value of the eggs; it appears likely that in future uniformity of color will be of much greater importance than lightness of color. Furthermore, there is some evidence that when the all-mash system is used, the hatchability of the eggs is more uniform. In any case, the all-mash system is satisfactory for caged or confined birds (fig. 2), as well as for those that have access to sunshine and green range. This system is usually the best one for the inexperienced poultryman.

THE MASH-GRAIN SYSTEM

As its name implies, the mash-grain system involves the feeding of both mash and grain. It yields the best results in the hands of the

Figure 2.—The all-mash system is satisfactory for caged or confined birds, as well as for those that have access to sunshine and green range. This system is usually the best one for the inexperienced poultryman.

skilled feeder. It is more flexible than the all-mash system and permits the poultryman who is familiar with the feed requirements of his birds to feed them accordingly.

There are several modifications of this system. As in the all-mash system, the oystershell or limestone grit may be fed separately or it may be ground fine and included in the mash. Likewise, wet mash may be fed for the purpose of maintaining or increasing feed consumption. When cod-liver oil or a similar source of vitamin D is required, it may be mixed and fed with the mash, as it usually is, or it may be mixed fresh each day with a portion of the grain. Yolk color may be controlled by using a mash and a grain mixture that have very nearly the same effect on it.

THE PELLET SYSTEM

The pellet system of feeding is in effect a modification of the all-mash system in that an all-mash diet is first prepared and then made into pellets. It may be modified in the same ways as the all-mash system. The advantages claimed for it are that it does not permit the birds to pick out some of the ingredients and leave the others, and that it tends to reduce the quantity of feed thrown from the hoppers and wasted. It does insure that all the birds will eat the same kind of feed, but at times the quantity of feed wasted may be as great as when the all-mash system is used.

THE GRAIN-MILK SYSTEM

When the grain-milk system is used the birds are usually given nothing but liquid skim milk or buttermilk to drink and are permitted to eat all the grain or grain mixture they want. Oystershell or limestone grit is fed in hoppers. The system is not suitable for feeding caged birds or birds otherwise confined. In general it is not recommended, but it may be used when plenty of good range is available and there is an abundance of liquid milk that, if not used in this manner, would have to be thrown away. This system may be used for both growing and laying chickens, but the former should be started on an all-mash diet. The feeding of the grain should be begun after the fourth week, the quantity being increased as rapidly as possible. The starting mash should not be discontinued abruptly but should be decreased gradually between the fourth and tenth weeks so that none is being fed by the end of the tenth week.

FEED FORMULAS

Some typical formulas are given in tables 1–4 for all-mash diets and mashes with which grain or a grain mixture is to be fed. In preparing these feed mixtures, careful attention should be given to the selection of the ingredients. Only feeding stuffs of good quality should be used. Except in the case of oats, barley, and feeding stuffs of high fiber content, the ingredients should not be finely ground.

MIXING THE INGREDIENTS

All the ingredients should be thoroughly mixed so that there will be a uniform distribution of those present in relatively small quantities. It is best to weigh out first the more bulky ingredients and those that are used in greatest quantity, and then the other ingredients may be added. It is a desirable practice to mix the salt and the other mineral supplements with some of the bran or middlings before adding them to the other ingredients. All oils should be mixed thoroughly with a suitable portion of the bran or ground corn before they are added. If pulverized or very finely ground oats are an ingredient, it is preferable to mix the oil with a portion of them, because finely ground oats tend to prevent destruction of the vitamin A in the oil.

ALL-MASH DIETS

Diets for Growing Chickens

The all-mash diets given in table 1 are suitable for the production of broilers and for the raising of breeding stock. Male birds to be marketed as roasters may be kept on these diets until they are of the proper weight. These diets may be fed to capons until they are 3 or 4 months old, after which, for the sake of economy, the protein content should be gradually reduced by the addition of increasing quantities of grain until the grain amounts to as much as 60 percent of the mixture. Pullets may be kept on these diets until within 5 or 6 weeks of the time egg production is expected to begin, at which time a suitable all-mash laying diet should be substituted at such a rate that nothing else is fed for the last week or two. Males that are to be used for breeding may be kept on these diets until they are placed with the females. However, if the males are not to be placed with the females until they are more than 9 months old, they may be fed diets that contain considerably less protein, minerals, and vitamins after the eighth or ninth month.

TABLE 1.—*All-mash starting and growing diets*

Ingredients	Diet 1	Diet 2	Diet 3	Diet 4
	Percent	*Percent*	*Percent*	*Percent*
Ground yellow corn	31.0	30.0	39.0	32.0
Finely ground oats or barley	10.0	10.0	10.0	
Wheat middlings	20.0	10.0	16.0	20.0
Wheat bran	6.0	10.0		15.0
Dried skim milk or dried buttermilk	6.0	10.0	10.0	5.0
Meat scrap (55-percent protein)	5.0	10.0	5.0	5.0
Fish meal	5.0		5.0	5.0
Alfalfa-leaf meal	7.0	8.0	5.0	6.0
Soybean meal	6.0	10.0		5.0
Corn-gluten meal				5.0
Cottonseed meal			8.0	
Linseed meal	2.0			
Ground limestone or oystershell	1.0	1.0	1.0	1.0
Salt mixture [1]	.5	.5	.5	.5
Cod-liver oil [2]	.5	.5	.5	.5
Total	100.0	100.0	100.0	100.0

[1] A mixture of 100 parts of common salt and 1.7 parts of anhydrous manganous sulfate (or 2.5 parts of manganous sulfate tetrahydrate).

[2] If a fortified cod-liver oil that contains 400 A. O. A. C. chick units of vitamin D and 3,000 International Units of vitamin A per gram is used, only 0.125 percent need be included in the diet.

A number of substitutions may be made in mixing the diets of table 1. Any of the cereal grains or grain sorghums may be substituted for the yellow corn and oats. Meat scrap and fish meal may be used interchangeably, but a good grade of fish meal is to be preferred to meat scrap unless it costs appreciably more. Cottonseed meal, peanut meal, corn-gluten meal, and soybean meal may be substituted one for the other, but soybean meal is preferable to the others. Sardine oil may be used in place of the cod-liver oil.

Diets for Laying and Breeding Chickens

As pointed out in the article on Practical Nutritive Requirements of Poultry (p. 787) it probably is always best to feed laying stock diets that will permit the production of eggs of high hatchability no matter whether the eggs are to be used for hatching or not. Accordingly all the diets given in table 2 are formulated for the production of eggs of high hatchability. However, good egg production may be obtained with diets that contain the quantities of vitamins A, D, and G that are suggested for laying stock in table 4 (p. 836).

Table 2.—*All-mash diets for laying and breeding stock*

Ingredients	Diet 5	Diet 6	Diet 7	Diet 8
	Percent	*Percent*	*Percent*	*Percent*
Ground yellow corn	37.2	41.0	44.0	39.5
Finely ground oats or barley	10.0	10.0	10.0	
Wheat middlings	20.0	10.0	16.0	20.0
Wheat bran	6.0	10.0		15.0
Dried skim milk or dried buttermilk	5.0	5.0	5.0	5.0
Meat scrap (55-percent protein)	2.0	4.0	2.0	2.0
Fish meal	2.0		2.0	2.0
Alfalfa-leaf meal	7.0	7.0	7.0	6.0
Soybean meal	2.5	4.5	5.0	2.0
Corn-gluten meal				2.0
Linseed meal (old process)	2.0	2.0	2.0	
Ground limestone or oystershell	3.3	3.0	2.5	3.5
Special steamed bonemeal	1.0	1.5	2.5	1.0
Salt mixture [1]	.6	.6	.6	.6
Cod-liver oil [2]	1.4	1.4	1.4	1.4
Total	100.0	100.0	100.0	100.0

[1] A mixture of 100 parts of common salt and 1.7 parts of anhydrous manganous sulfate (or 2.5 parts of manganous sulfate tetrahydrate).

[2] If a fortified cod-liver oil that contains 400 A. O. A. C. chick units of vitamin D and 3,000 International Units of vitamin A per gram is used, only 0.35 percent need be included in the diet.

Several substitutions may be made in mixing the all-mash laying and breeding diets in table 2. If it is desirable to lighten the color of the yolks of the eggs, white corn or any of the other grains or grain sorghums may be substituted for the yellow corn. If the color of the yolks is to be further lightened, the alfalfa-leaf meal may be reduced to 5 percent by substituting an equal weight of dried skim milk or dried whey for the amount omitted. Meat scrap and fish meal may be used interchangeably. Peanut meal, corn-gluten meal, and soybean meal may be substituted one for the other.

MASHES WITH WHICH GRAIN IS TO BE FED

In compounding mashes with which grain is to be fed, it is necessary to make suitable allowance [illegible] the fact that the various grains are relatively poor sources of vitamin G. Likewise, when grains other than yellow corn are used, the vitamin A content of the mash should be somewhat greater than it need be otherwise. Because grains supply virtually no vitamin D, all mashes that are to be fed with grain should contain about twice as much vitamin D as all-mash diets. Care must also be taken to insure that the combination of mash and grain supplies the proper quantities of calcium and phosphorus.

Mashes for Growing Chicks

The starting and growing mashes given in table 3 are intended for use when the mash-grain system of feeding is used. Finely cracked corn or other grain may be fed simultaneously with these mashes any time after the chicks are 2 weeks old. Only a small quantity of grain should be fed at first, but the quantity may be gradually increased until approximately equal quantities of grain and mash are being fed by the time the chickens are 14 to 16 weeks old. Any suitable mixture of grains may be used, such as one consisting of equal parts by weight of corn and wheat, of corn and oat groats, or of corn, wheat, and oat groats. After the chickens are 6 to 8 weeks old, whole oats may be used in place of the oat groats and coarsely cracked corn may be used in place of the more finely cracked corn. After the chickens are about 12 weeks old whole corn may be fed.

Table 3.—*Starting and growing mashes with which grain or a grain mixture is to be fed*

Ingredients	Mash 9	Mash 10	Mash 11	Mash 12
	Percent	*Percent*	*Percent*	*Percent*
Ground yellow corn	17.7	18.9	25.3	17.5
Finely ground oats or barley	10.0	12.0	10.0	
Wheat middlings	20.0	12.0	20.0	30.0
Wheat bran	8.0	12.0		10.0
Dried skim milk or dried buttermilk	10.0	10.0	10.0	10.0
Meat scrap (55-percent protein)	6.0	10.0	5.0	5.0
Fish meal	6.0		5.0	4.0
Alfalfa-leaf meal	10.0	10.0	10.0	10.0
Soybean meal	4.0	10.0		4.0
Corn-gluten meal				4.0
Cottonseed meal			10.0	
Linseed meal (old process)	3.0			
Ground limestone or oystershell	1.3	1.1	1.7	2.0
Special steamed bonemeal	2.0	2.0	1.0	1.5
Salt mixture [1]	1.0	1.0	1.0	1.0
Cod-liver oil [2]	1.0	1.0	1.0	1.0
Total	100.0	100.0	100.0	100.0

[1] A mixture of 100 parts of common salt and 1.7 parts of anhydrous manganous sulfate (or 2.5 parts of manganous sulfate tetrahydrate).

[2] If a fortified cod-liver oil that contains 400 A. O. A. C. chick units of vitamin D and 3,000 International Units of vitamin A per gram is used, only 0.25 percent need be included in the mash.

In mixing the mashes given in table 3, any grain, grain sorghum, or a mixture of grains and grain sorghums may be used in place of the yellow corn; meat scrap and fish meal may be used interchangeably; cottonseed meal, peanut meal, corn-gluten meal, and soybean meal may be substituted one for the other; and sardine meal may be used in place of cod-liver oil.

Mashes for Laying and Breeding Stock

For the best results, an equal quantity of grain should be fed with the laying and breeding mashes given in table 4. Oystershell or limestone grit should never be given to the chickens when these mashes are used. Either whole or cracked corn may be fed with these mashes; but, if desired, mixtures of corn and oats or of corn, wheat, and oats, or mixtures containing the grain sorghums may be used.

A few substitutions may be made in mixing the mashes given in table 4. Any grain may be substituted for the oats or barley in mashes 13, 14, and 15. Either meat scrap or fish meal may be used to the exclusion of the other. Peanut meal, corn-gluten meal, and soybean meal may be substituted one for the other; but if light-colored yolks are desired, corn-gluten meal should not be used. If it is desirable to lighten the color of the yolks, a grain mixture that contains no yellow corn may be used. Further reduction of yolk color may be had by replacing a third of the alfalfa-leaf meal with an equal weight of dried skim milk or dried whey. Sardine oil may replace the cod-liver oil.

TABLE 4.—*Laying mashes with which grain or a grain mixture is to be fed*

Ingredients	Mash 13	Mash 14	Mash 15	Mash 16
	Percent	*Percent*	*Percent*	*Percent*
Finely ground oats or barley	17.5	19.0	23.3	
Wheat middlings	15.0	15.0	20.0	31.5
Wheat bran	12.0	10.0		20.0
Dried skim milk or dried buttermilk	10.0	10.0	10.0	10.0
Meat scrap (55-percent protein)	4.7	10.0	5.0	4.5
Fish meal	4.7		5.0	5.0
Alfalfa-leaf meal	14.0	15.0	15.0	12.0
Soybean meal	5.5	5.0	5.3	2.3
Corn-gluten meal				2.4
Linseed meal (old process)	4.0	4.0	4.0	
Ground limestone or oystershell	5.9	5.6	5.3	6.8
Special steamed bonemeal	2.7	2.4	3.1	1.5
Salt mixture [1]	1.2	1.2	1.2	1.2
Cod-liver oil [2]	2.8	2.8	2.8	2.8
Total	100.0	100.0	100.0	100.0

[1] A mixture of 100 parts of common salt and 1.7 parts of anhydrous manganous sulfate (or 2.5 parts of manganous sulfate tetrahydrate).

[2] If a fortified cod-liver oil that contains 400 A. O. A. C. chick units of vitamin D and 3,000 International Units of vitamin A per gram is used, only 0.7 percent need be included in the mash.

FEED MIXTURES FOR TURKEYS

Inasmuch as turkeys are usually raised under somewhat different conditions from those under which chickens are raised, and as very young turkeys require somewhat more protein, vitamin A, and vitamin D, a series of special formulas of feed mixtures for this species is given in table 5.

TABLE 5.—*Feed mixtures for turkeys*

Ingredients	Starting mashes		Growing mashes			All-mash laying diets	
			No range	Fair range	Good range	No range	Range
	17	18	19	20	21	22	23
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Ground yellow corn	18	15	20	34	25	30.0	30.0
Finely pulverized oats or barley	15	20	15	12	25	20.0	20.0
Wheat middlings or shorts	12	12	15	12	20	22.0	24.5
Wheat bran	12	10	10	12	10	5.0	6.0
Dried skim milk or dried buttermilk	10	7	10	10		5.0	4.0
Meat scrap (55-percent protein)	13	7	5	13	19	4.0	3.5
Fish meal (preferably sardine)	8	7				3.0	2.0
Alfalfa-leaf meal	10	10	10	6		5.0	4.5
Corn-gluten meal		10	10				
Ground limestone or oystershell			2			4.0	4.0
Special steamed bonemeal			2				
Salt or salt mixture [1]	1	1	1	1	1	.5	.5
Cod-liver oil [2]	1	1				1.5	1.0
Total	100	100	100	100	100	100.0	100.0

[1] To prevent perosis, it is desirable that the starting mashes and the all-mash laying diets contain some added manganese. To supply this manganese, use a mixture of 100 parts of common salt and 1.7 parts of anhydrous manganous sulfate (or 2.5 parts of manganous sulfate tetrahydrate).

[2] If a fortified cod-liver oil that contains 400 A. O. A. C. chick units of vitamin D and 3,000 International Units of Vitamin A per gram is used, only one-fourth as much need be included in the mashes and all-mash diets.

A starting mash should be fed until the poults are 8 weeks old and then a suitable growing mash should be fed. It is desirable to begin the feeding of cracked corn, or a mixture of cracked grains, after the poults are 2 weeks old. After changing to the growing mashes, any grain or grain mixture may be fed, but it is desirable to use a grain mixture that contains 50 to 75 percent of oats. No grain should be fed with the all-mash laying diets. It is unnecessary and undesirable to feed ground limestone or oystershell grit with any of these feed mixtures; however, it is desirable to supply gravel or other insoluble grit.

MANAGEMENT

Management is an important factor in the economical and efficient feeding of poultry. Abrupt changes in diet, insufficient hopper space, the use of stale feed, and poorly lighted houses all tend to decrease feed consumption and hence to retard growth or slow up the rate of egg production. Thus, attention to what may be considered as minor details may at times mean the difference between success and failure in poultry raising.

When poultry is kept without access to the soil and to sunshine, much more attention must be given to the diet. This is accounted for in part by the facts that sunshine may serve as a source of some or even all the vitamin D that is required and that the green growing grass and other plants may serve as sources of all the other vitamins. Furthermore, poultry that has access to the soil (fig. 3) is less likely to suffer from a deficiency of some of the mineral elements, for example, manganese, than is poultry that is kept off the soil.

Feed left in the hoppers from the preceding day is usually not so palatable as fresh feed; therefore it is good practice to give the birds only a little more feed each day than they will eat. The fresh feed should be mixed in the hoppers with the small residues from the previous feedings so that there will be no accumulation of old feed at the bottoms of the hoppers. Furthermore, if the feed mixture contains cod-liver oil or other fish oil, no more than can be fed within 10 days or two weeks should be mixed at one time. This precaution should be observed very carefully when the oil is depended on as the chief source of vitamin A.

Abrupt changes in the diet are to be avoided in the feeding of laying stock, especially after the peak of production is reached, because they may cause the birds to begin molting somewhat earlier than they would otherwise. If for any reason a change in diet must be made, it should be made gradually over a period of at least a week or 10 days.

It is very important that there be sufficient hopper space, otherwise the birds may not be able to get all the feed they require. If throughout the day the birds are crowded around the hoppers, more hoppers should be used. Careful observation of the birds at the feed hoppers is the best guide to follow in providing hopper space.

It is a common practice, when grain or a grain mixture is used, to feed it in the litter in order to give the birds some exercise in obtaining their feed. Experience gained by feeding chickens in batteries indicates, however, that the value of this exercise has been overrated very much. In any case, the feeding of grain in the litter is to be

Figure 3.—Good range may be used to cut the cost of production and make feeding easier. Experimental grass plots for poultry at the Agricultural Research Center, Beltsville, Md.

condemned as an insanitary practice. The better practice is to feed all grain, or so-called scratch feed, in hoppers.

When birds are confined in houses, attention should be given to lighting. If the houses are poorly lighted, feed consumption may be adversely affected. Artificial lighting is sometimes used to increase the length of the feeding day during the fall and winter. Properly used, artificial lighting tends to increase the production of eggs during the fall and to maintain it during the winter. Apparently, however, it has little effect on the total annual egg production. If artificial lighting is to be used, it should be started about the first of October, and at times it may be advantageously started somewhat earlier. The total period of light from both natural and artificial sources should be about 14 hours. Both morning and evening lighting may be used to lengthen the feeding day, but unless dimming devices are used to end the evening lighting, it is best to use artificial light only in the morning.

APPENDIX

TABLE 6.—*Average composition of some feedstuffs used in the feeding of poultry*

Feedstuff	Moisture	Ash	Crude protein	Carbohydrates		Fat, or other extract
				Crude fiber	Nitrogen-free extract	
Grains and seeds	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Barley	10.4	2.9	11.8	5.9	66.9	2.1
Barley (Pacific Coast States)	10.1	2.6	8.7	5.7	71.0	1.9
Beans, navy	13.4	3.6	22.7	5.8	53.0	1.5
Beans, pinto	9.1	4.5	22.7	4.5	58.0	1.2
Bread	33.8	1.5	7.9	.7	55.4	.7
Brewers' grains, dried	7.0	3.7	26.2	14.7	41.8	6.6
Broomcorn	11.6	3.1	10.5	8.3	63.0	3.5
Buckwheat	11.9	1.8	10.1	10.4	63.5	2.3
Buckwheat middlings	11.4	4.7	28.6	6.0	42.2	7.1
Coconut meal (old process)	9.3	6.1	20.5	11.1	44.7	8.3
Corn	11.9	1.3	9.3	2.1	71.2	4.2
Corn, Argentine	11.0	1.7	11.0	1.8	68.8	5.7
Corn bran	9.9	2.3	9.9	9.6	61.6	6.7
Corn meal	11.2	.9	8.8	1.1	75.5	2.5
Corn-gluten feed	9.7	6.1	25.9	7.2	48.5	2.6
Corn-gluten meal	8.9	1.5	43.0	2.6	42.1	1.9
Cottonseed meal (41-percent protein)	7.5	5.8	41.8	11.4	27.1	6.4
Cowpeas	11.1	3.5	23.5	4.1	56.3	1.5
Distillers' grains (corn)	7.0	2.3	31.2	11.5	37.5	10.5
Durra	10.0	2.0	10.2	1.7	72.6	3.5
Feterita	10.2	1.6	13.2	1.8	70.2	3.0
Field peas	9.3	3.3	23.3	5.9	57.0	1.2
Flaxseed	10.3	4.4	22.3	7.1	23.1	32.8
Garden peas	11.8	3.0	25.6	4.4	53.6	1.6
Hempseed	7.6	5.9	22.9	18.6	18.4	26.6
Hempseed meal	7.3	7.8	31.7	23.9	25.3	4.0
Hominy (pearled)	11.8	.7	7.4	.6	77.6	1.9
Hominy feed	8.8	2.9	11.0	5.1	65.5	6.7
Kafir	11.7	1.6	11.5	2.0	70.1	3.1
Linseed meal (old process)	9.4	5.8	35.3	8.5	35.0	6.0
Malt sprouts	7.9	5.9	26.0	13.0	45.7	1.5
Millet (proso)	9.6	3.4	11.6	8.7	63.1	3.6
Milo	11.0	2.0	11.0	2.2	70.9	2.9
Oats	10.1	3.4	11.2	11.3	59.5	4.5
Oatmeal, or rolled oats	8.6	2.2	16.2	2.1	64.2	6.7
Peanuts (hulls on)	6.0	2.8	24.8	17.8	14.0	34.6
Peanut kernels	5.4	2.3	30.4	2.7	11.6	47.6
Peanut meal (no hulls) (old process)	6.9	5.6	45.7	9.2	24.0	8.6
Rice (whole)	10.3	4.7	7.9	8.8	66.3	2.0
Rice (polished)	11.8	.5	7.5	.4	79.4	.4
Rice bran	8.8	10.9	13.0	12.5	41.1	13.7
Rye	10.7	2.0	11.5	2.1	72.0	1.7
Soybeans	8.8	4.8	37.9	5.0	26.6	16.9
Soybean meal	9.1	5.6	43.9	5.9	30.0	5.5

TABLE 6.—*Average composition of some feedstuffs used in the feeding of poultry*—Con.

Feedstuff	Moisture	Ash	Crude protein	Carbohydrates		Fat, or other extract
				Crude fiber	Nitrogen-free extract	
Grains and seeds—Continued	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Shallu	10.0	1.8	12.9	1.8	70.0	3.5
Sunflower seed	7.4	3.4	16.0	28.6	21.4	23.2
Sunflower seeds (hulled)	5.0	3.8	28.0	6.0	16.2	41.0
Velvetbeans	10.0	3.0	24.8	6.2	50.8	5.2
Wheat	11.0	1.8	12.4	2.4	70.5	1.9
Wheat bran	10.2	5.9	15.6	9.0	55.1	4.2
Wheat flour	12.9	.4	10.7	.4	74.2	1.4
Whear-flour middlings	10.5	3.5	17.0	5.1	59.3	4.6
Wheat-germ meal	8.7	4.6	28.9	2.7	44.7	10.4
Wheat middlings, standard	11.1	4.1	16.9	6.6	56.6	4.7
Wheat red-dog flour	10.2	2.7	16.9	3.2	62.6	4.4
Wheat shorts (gray)	10.3	4.1	17.6	5.5	58.0	4.5
Feeds of animal origin						
Beef scrap	6.5	21.5	58.0	2.2	.7	11.1
Bonemeal, steamed	3.1	73.8	13.0	.8	2.8	6.5
Bonemeal, special steamed	3.1	85.1	6.5	2.6	2.1	.6
Buttermilk	90.8	.8	3.2	.0	4.6	.6
Buttermilk, condensed	71.6	3.5	10.6	.0	12.2	2.1
Buttermilk, dried	7.1	10.1	33.4	.4	44.0	5.0
Crab meal	8.1	40.1	34.7	8.5	6.5	2.1
Fish meal (average of unidentified fish meals)	8.0	19.7	60.4	.7	3.5	7.7
Fish meal, herring	9.1	12.1	66.0	.6	3.0	9.2
Fish meal, menhaden	8.0	20.4	57.5	.8	4.1	9.2
Fish meal, whitefish (high ash)	7.8	26.0	61.6	.4	1.2	3.0
Fish meal, whitefish (low ash)	12.1	17.6	60.9	.6	.1	8.7
Fish meal, sardine	8.0	15.0	67.0	.4	3.6	6.0
Fish meal, tuna	5.0	20.2	60.7	.4	5.1	8.6
Liver meal, Argentine	5.0	5.0	65.4	.8	9.8	14.0
Meat scrap (55-percent protein)	6.7	24.2	55.2	2.2	1.0	10.7
Meat-and-bone scrap (50-percent protein)	6.0	29.2	50.0	2.1	1.8	10.9
Pork liver, dried	4.8	5.3	63.7	.4	15.0	10.8
Pork cracklings	5.0	2.3	56.4	.0	4.1	32.2
Shrimp meal (or bran)	11.0	33.9	42.0	9.5	1.4	2.2
Skim milk	90.5	.7	3.5	.0	5.1	.2
Skim milk, dried	6.0	7.9	35.0	.0	50.0	1.1
Tankage (60-percent protein)	8.0	19.5	59.8	2.7	1.8	8.2
Whey	93.7	.6	.8	.0	4.9	.0
Whey, dried	6.3	8.5	12.5	.3	71.7	.7
Green feeds, etc.						
Alfalfa, fresh	73.8	2.5	4.6	7.5	10.7	.9
Alfalfa-leaf meal	7.8	12.0	20.4	17.1	40.1	2.6
Alfalfa meal	8.3	8.7	16.0	27.3	37.2	2.5
Beet pulp, dried	9.0	3.3	9.3	19.1	58.5	.8
Cabbage	90.8	.8	1.8	1.1	5.2	.3
Cane molasses	24.8	8.2	3.0	.0	64.0	.0
Carrots	88.4	1.1	1.1	1.2	7.9	.3
Grapefruit refuse, dried	9.3	4.3	4.8	11.6	68.7	1.3
Kale	88.4	1.9	2.4	1.5	5.3	.5
Mangels	90.1	1.1	1.5	.8	6.4	.1
Orange peel, dried	14.0	4.1	5.8	10.6	64.8	.7
Orange-pulp meal	10.8	3.4	7.5	8.9	67.9	1.5
Potatoes	78.8	.9	2.0	.5	17.7	.1
Rape	84.6	2.2	2.6	2.4	7.6	.6
Red clover hay	12.3	6.7	12.7	25.7	39.6	3.0
Rutabagas	88.8	1.0	1.2	1.5	7.3	.2
Turnips	90.6	.8	1.3	1.1	6.0	.2
Yeast, brewers', dried	7.0	7.3	46.5	1.1	35.3	2.8

TABLE 7.—*Average calcium, phosphorus, and manganese content of some feedstuffs used in the feeding of poultry*

Feedstuff	Calcium (Ca)	Phosphorus (P)	Manganese (Mn)
Grains and seeds	*Percent*	*Percent*	*Parts per million*
Barley	0.05	0.36	16
Beans, navy	.16	.45	13
Bread	.03	.10	4
Brewers' grains, dried	.20	.46	20
Buckwheat	.06	.43	80
Coconut meal (old process)	.29	.64	85
Corn	.01	.29	5
Corn bran	.03	.20	16
Corn-gluten feed	.13	.64	24
Corn-gluten meal	.06	.40	4
Corn meal	.01	.30	4
Cottonseed meal (41-percent protein)	.23	1.18	18
Cowpeas	.10	.46	30
Distillers' grains (corn), dried	.04	.30	20
Feterita	.02	.32	(1)
Field peas	.08	.40	30
Flaxseed	.25	.66	35
Garden peas	.08	.40	30
Hempseed meal	.22	.87	(1)
Hominy	.01	.08	2
Hominy feed	03	.51	16
Kafir	.03	.35	16
Linseed meal (old process)	.33	.74	40
Malt sprouts	.18	70	35
Millet (proso)	.01	.33	35
Milo	.04	.32	15
Oats	.10	.36	34
Oatmeal, or rolled oats	.08	.44	20
Peanut kernels	07	.39	(1)
Peanut meal (old process)	.18	.56	(1)
Rice (polished)	.01	09	12
Rice bran	.10	1.84	280
Rye	.05	.36	40
Soybeans	20	.53	31
Soybean meal	29	69	30
Sunflower seed	.41	.99	(1)
Wheat	.04	.39	39
Wheat bran	.11	1.21	119
Wheat flour	.02	.11	4
Wheat-flour middlings	.07	.69	113
Wheat-germ meal	.07	1.01	160
Wheat middlings, standard	.08	93	119
Wheat red-dog flour	.07	.59	35
Wheat shorts	.08	.93	60
Feeds of animal origin			
Beef scrap	7.23	3.73	5
Buttermilk, liquid	.18	.10	Trace
Buttermilk, condensed	.56	.33	0.2
Buttermilk, dried	1.56	1.05	.4
Crab meal	13.25	.50	(1)
Feeds of animal origin—Continued			
	Percent	*Percent*	*Parts per million*
Fish meal (average of unidentified fish meals)	6.50	3.60	45
Fish meal, herring	3.83	2.50	(1)
Fish meal, whitefish (high ash)	9.09	4.70	(1)
Fish meal, whitefish (low ash)	5.84	3.04	(1)
Fish meal, sardine	4.73	2.63	40
Fish meal, tuna	6.25	3.46	(1)
Liver meal, Argentine	.11	.90	4
Meat-and-bone scrap (50-percent protein)	10.20	4.91	10
Meat scrap (55-percent protein)	8.25	4.00	18
Pork liver, dried	.06	1.12	4
Skim milk, liquid	.13	.11	Trace
Skim milk, dried	1.27	.96	0.6
Tankage (60-percent protein)	7.16	3.53	14
Whey, liquid	.05	.04	1
Whey, dried	.83	.70	14
Green feeds, etc.			
Alfalfa (green)	.42	.07	7
Alfalfa-leaf meal	1.90	.22	30
Alfalfa meal	1.44	.21	26
Beet pulp, dried	.70	.07	23
Cabbage	.07	.04	21
Cane molasses	56	.06	(1)
Carrots	06	.07	(1)
Grapefruit refuse, dried	.74	.10	(1)
Kale	18	.07	(1)
Orange peel, dried	73	.11	(1)
Orange-pulp meal	64	.10	(1)
Potatoes	.02	.06	3
Rape	.34	.07	50
Red clover hay	1.17	.18	40
Rutabagas	.06	.04	(1)
Turnips	.05	.05	(1)
Yeast, dried	1.26	1.21	2
Calcium, phosphorus, and manganese supplements			
Bone, fresh	22.95	10.42	12
Bonemeal	27.00	13.00	13
Bonemeal, steamed	28.80	13.34	5
Bonemeal, special steamed	31.30	14.49	2
Crab shell	23.74	2.55	300
Gypsum	25.00	Trace	(1)
Limestone, high-calcium	39.20	00	200
Oystershell, washed	38.00	Trace	100
			Percent
Manganous sulfate, anhydrous	00	.00	36.3
Manganous sulfate, tetrahydrate	00	.00	24.6

[1] Information lacking.

Table 8.—*Average digestibility in the chicken of some feedstuffs used in the feeding of poultry*

Feedstuff	Organic matter	Crude protein	Crude fiber	Nitrogen-free extract	Fat, or ether extract	Total digestible nutrients
Grains and seeds	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Barley	76	75	7	83	62	68
Buckwheat	72	59	8	85	87	65
Corn, whole or cracked	87	76	12	90	86	80
Corn, ground	88	79	6	92	88	81
Corn meal	87	74	7	90	89	80
Corn, Argentine, whole or cracked	88	84	16	91	81	83
Corn, Argentine, ground	88	83	13	91	91	84
Cottonseed meal	72	76	12	86	86	69
Cowpeas	75	55	12	87	89	65
Feterita	89	88	33	91	81	82
Field peas	74	76	12	80	80	66
Garden peas	83	88	10	86	86	72
Kafir	90	84	19	93	80	81
Millet	78	76	17	87	78	72
Milo	89	83	31	92	78	80
Mixed feed (laying mash)	85	85	44	88	92	83
Oats	66	74	12	74	84	62
Oatmeal, or rolled oats	87	79	14	91	92	85
Rice (whole)	74	75	5	84	72	65
Rice bran	52	60	3	52	87	41
Rye	79	68	8	84	27	60
Soybeans	79	74	20	93	86	86
Soybean meal	77	83	2	82	82	71
Shallu	90	78	39	94	85	83
Wheat	82	75	8	87	50	73
Wheat bran	46	66	9	47	42	41
Wheat middlings	54	65	8	55	54	48
Wheat shorts	68	69	13	71	85	63
Feeds of animal origin						
Beef scrap	90	92	------	---------	94	77
Buttermilk, dried	81	82	------	81	78	72
Fish meal	90	91	------	---------	94	71
Meat scrap and meat-and-bone meal	87	90	------	---------	93	70
Skim milk, dried	87	90	------	85	95	76
Tankage	85	85	------	---------	96	69
Green feeds, etc.						
Alfalfa-leaf meal	30	99	4	---------	---------	-------
Alfalfa meal	29	64	2	34	22	25
Beet pulp, dried	17	37	0	19	0	15
Potatoes	75	47	6	84	---------	16
Clover hay	23	71	10	14	36	20

Table 9.—*Average vitamin content of some feedstuffs used in the feeding of poultry*

Feedstuff	Vitamin A per pound	Vitamin B_1 per pound	Vitamin D per pound[1]	Vitamin E[2]	Vitamin G (riboflavin) per pound	Chick antidermatosis factor per pound
Grain and seeds	*International Units*	*International Units*	*A.O.A.C. chick units*[3]		*Micrograms (gammas)*[4]	*Modified Jukes-Lepkovsky units*[5]
Barley	400	250	Trace	++	400	0.7
Beans, navy	(6)	250	---------	(6)	(6)	.1
Beans, pinto	(6)	2,270	---------	(6)	(6)	(6)
Bread	50	10	---------	(6)	(6)	(6)
Buckwheat	(6)	500	---------	(6)	300	(6)
Corn, yellow	3,180	270	---------	++	450	.7
Corn, white	0	270	---------	++	450	.7
Corn-gluten meal (yellow)	6,800	(6)	---------	0	0	(6)
Cottonseed meal (41-percent protein)	600	1,800	---------	(6)	300	1.0
Cowpeas	1,360	450	---------	(6)	350	1.3
Field peas	2,720	450	---------	(6)	(6)	(6)
Garden peas	4,540	450	---------	++	(6)	1.5
Hempseed meal	(6)	(6)	---------	++	1,100	1.0

See footnotes at end of table.

TABLE 9.—*Average vitamin content of some feedstuffs used in the feeding of poultry*—Continued

Feedstuff	Vitamin A per pound	Vitamin B$_1$ per pound	Vitamin D per pound [1]	Vitamin E [2]	Vitamin G (riboflavin) per pound	Chick antidermatosis factor per pound
	International Units	*International Units*	*A.O.A.C. chick units* [3]		*Micrograms (gammas)* [4]	*Modified Jukes-Lepkovsky units* [5]
***Grain and seeds**—Continued*						
Kafir	250	(6)	---------	(6)	(6)	(6)
Linseed meal (old process)	200	2,000	---------	+	900	0.1
Milo	250	(6)	---------	(6)	400	.7
Oats	80	270	---------	++	400	.7
Oatmeal, or rolled oats	(6)	230	---------	++	(6)	.8
Peanuts (hulls on)	(6)	900	---------	++	950	3.5
Peanut kernels	(6)	1,500	---------	++	1,200	4.0
Peanut meal, no hulls (old process)	250	900	---------	++	1,200	4.0
Rice bran	(6)	1,500	---------	(6)	900	1.8
Rye	(6)	250	---------	++	(6)	(6)
Soybeans	600	1,100	---------	(6)	1,300	1.0
Soybean meal	170	900	Trace	(6)	1,400	1.0
Wheat	140	340	---------	++	400	.7
Wheat bran	150	450	---------	++	1,000	1.8
Wheat flour	(6)	10	---------	(6)	(6)	(6)
Wheat-germ meal	1,900	1,930	---------	++++	1,800	.5
Wheat-flour middlings	100	800	---------	++	700	.7
Wheat middlings, standard	120	1,000	---------	+++	900	.8
Wheat red-dog flour	60	(6)	---------	(6)	450	(6)
Wheat shorts	120	1,000	---------	+++	900	.8
Feeds of animal origin						
Buttermilk, liquid	25	40	(6)	(6)	1,200	.3
Buttermilk, dried	200	400	Trace	+	9,000	3.0
Buttermilk, sweet cream, dried	200	400	Trace	+	14,000	3.0
Cod-liver oil	[7] 340,190	0	[7] 45,360	0	0	0
Cod-liver oil, fortified	1,362,000	0	181,600	(6)	0	0
Fish meal, white	(6)	(6)	(6)	(6)	4,500	.2
Fish meal, sardine	(6)	(6)	(6)	(6)	3,200	.2
Fish meal, menhaden	(6)	(6)	(6)	(6)	2,250	.2
Liver meal, Argentine	(6)	(6)	(6)	(6)	18,500	8.0
Meat scrap	(6)	(6)	---------	(6)	2,700	.2
Pork liver, dried	47,670	170	200	(6)	45,360	10.0
Sardine (pilchard) oil	45,240	(6)	45,360	(6)	0	0
Skim milk, liquid	15	40	---------	+	1,000	.3
Skim milk, dried	130	400	---------	+	9,500	2.5
Tankage	(6)	(6)	---------	(6)	800	(6)
Whey, dried	(6)	(6)	---------	(6)	12,000	4.0
Green feeds, etc.						
Alfalfa (green)	63,560	225	---------	++	2,000	.1
Alfalfa-leaf meal, dehydrated	95,000	450	---------	+++	8,000	3.0
Alfalfa-leaf meal	32,000	400	14	+++	7,000	2.0
Alfalfa meal	13,000	400	---------	+++	5,000	1.5
Cabbage	200	100	---------	(6)	100	(6)
Cane molasses	(6)	(6)	---------	(6)	2,000	6.0
Carrots	18,200	100	---------	(6)	120	.1
Kale	181,400	100	---------	(6)	2,240	(6)
Potatoes	220	80	---------	(6)	55	(6)
Red clover hay	9,000	450	---------	+++	(6)	(6)
Turnips	(6)	70	---------	(6)	45	(6)
Yeast, brewers', dried	(6)	4,500	---------	0	16,000	15.0

[1] Leaders (---------) mean that the feedstuff contains no appreciable quantity of vitamin D.

[2] The symbols in this column have the following meanings: + Fair source of vitamin E; ++ Good source of vitamin E; +++ Very good source of vitamin E; ++++ Excellent source of vitamin E.

[3] This is the official unit of the Association of Official Agricultural Chemists. It is equivalent to 1 international Unit of the kind of vitamin D found in pure cod-liver oil.

[4] A microgram, or gamma, is one-millionth of a gram; it is equal to approximately one twenty-eight millionth of an ounce.

[5] The modification consists in giving the same value to a pound of the feedstuff as was originally given to a gram. In order that a diet may supply enough of the chick antidermatosis factor, it should contain not less than 0.9 modified Jukes-Lepkovsky unit per pound.

[6] Information on vitamin content is lacking.

[7] Cod-liver oil, if it is to be sold legally as such in interstate commerce, must contain at least 272,150 International Units of vitamin A and 38,590 International Units of vitamin D per pound. The vitamin A content of cod-liver oil varies from 272,150 to about 1,000,000 International Units per pound and the vitamin D content from 38,590 to about 160,000 units per pound. Cod-liver oil and other vitamin-bearing fish oils should be purchased only from reliable sources and should be used according to the manufacturer's guarantee of their vitamin potency.

NUTRITIONAL REQUIREMENTS OF DOGS

by Imogene P. Earle [1]

HERE is a discussion of the nutrition of dogs from the theoretical standpoint. It deals with such questions as whether or not they must have an all-meat diet; whether or not they can digest carbohydrates; what are the proper proportions of protein, fat, and carbohydrate in the diet; what their energy needs are in terms of calories; and what are their quantitative needs for minerals and vitamins. The practical feeding of dogs is taken up in a later article.

THE DOG in his natural state was a carnivorous animal subsisting almost entirely on the flesh, bones, blood, and viscera of animal carcasses and living under conditions in which abundant exercise and free access to sunlight, soil, and green leaves played an important part. During the process of his domestication, however, he has had imposed on him a different set of conditions. Generally speaking, the amount of his exercise has been reduced, he has been restricted in his access to sunlight, and his dietary habits have for the most part become those of the omnivores, which live on both animal and vegetable foods.

Under these new and artificial conditions the dog is far more subject to nutritional-deficiency diseases than under natural conditions. Such diseases, in the light of present knowledge, can usually be easily recognized in their acute stages and may be prevented or cured by correcting the deficiency. However, deficiencies so marked and extreme as to produce acute disease undoubtedly occur much less often than partial and perhaps multiple deficiencies which result in lowered vitality, decreased appetite, dull coat, impaired reproductive functions, decreased rate of growth in the young, and other signs of general ill health. These symptoms are such as can be attributed either to infection or to malnutrition and their correlation with feeding practices is difficult.

The nutritive requirements of the dog have received an increasing amount of attention and interest within the past few years. Dog races and dog shows have grown in popularity, and as scientific knowledge of the fundamentals of nutrition has increased, the breeders and owners of racing and show dogs, and of pets and working dogs as well, have become more conscious of the importance of nutrition in the health and performance of their animals. In recent years the preparation of dog foods has grown to remarkable proportions as an industry. The manufacturers are concerned with knowing the composition of adequate rations on which a profit can be made, and in some instances they have carried out experimental work in testing the efficiency of their products in the nutrition of dogs. Veterinarians also have been interested in the proper nutrition of the dog, since they recognize that a large percentage of their canine patients are suffering from ills of nutritional origin.

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Although the amount of scientific investigation concerned primarily with the food requirements of the dog has not been great, the dog has been used as a laboratory animal in fundamental nutrition studies more extensively than any other domestic animal. As a result a good deal is known about many aspects of his nutrition such as vitamin requirements, both qualitative and quantitative; bone and tooth formation; and ability to digest and utilize carbohydrates. His energy requirements can be calculated from the standards of Dechambre, as reported by Linton (*687*),[2] and of Brody, Procter, and Ashworth (*157*). While little that is specific is known about his mineral requirements, estimates of his needs for minerals are made on the basis of the requirements established for human nutrition. Information regarding his specific protein requirements is meager, and estimates of his protein needs and of the proportions in which protein, fat, and carbohydrate should be combined in his diet have been based for the most part on the composition of diets that have been found in practice to be satisfactory.

In spite of the results of many studies involving the nutrition of the dog, there is a great divergence of opinion among veterinarians and dog breeders concerning the feeding of dogs. For example, Quitman (*940*) after more than 40 years of veterinary practice in which he states he has treated approximately 50,000 dogs, 20 percent of which were suffering from ills of dietetic origin, has concluded that dogs do best on a meat diet exclusively and that they do not digest starchy or vegetable foods. Spaulding (*1092*), in his paper on the proper feeding of dogs, has stated that 75 percent of dogs have difficulty in digesting vegetables and has recommended a diet in which meat is used in large proportions but is supplemented by cooked cereals in the form of biscuit. He further advised against the use of any sloppy or mushy foods. There is ample support in the veterinary journals for these views regarding the indigestibility of vegetables from the point of view of supplying energy and protein needs. The function of vegetables in the diet as an important source of vitamins and minerals is fairly generally recognized. Some veterinarians agree with Quitman that no carbohydrates in the form of cereals or vegetables should be included in the dog's diet. Many others allow a limited amount of carbohydrate foods, but there is diversity of opinion as to kind and amount. There is, however, fair agreement among the veterinarians that meat is the essential basis of all successful diets.

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[2] Italic numbers in parentheses refer to Literature Cited, p. 10 5.7

Contrary to these opinions regarding the indigestibility of vegetables and the inadvisability of feeding sloppy food are the excellent results cited by Linton (*687*), obtained at the greyhound-racing establishments of England where the dogs are fed relatively large quantities of vegetables which are cooked and fed as slop. And in contradiction to the belief that meat is essential to a successful diet are the satisfactory results reported by Cowgill (*233*), Morgan (*813*), and many others from the use of meat-free diets in the laboratory.

An attempt is made here to correlate some established facts concerning the physiology and nutritive requirements of dogs with results of observations on practical feeding that are often seemingly contradictory.

PHYSIOLOGY OF DIGESTION IN THE DOG

The teeth of the dog are typical of those of the carnivores. Food is bolted without chewing and there is no digestion in the mouth.

The capacity of the stomach is quite large in relation to the size of the body and to the capacity of the intestines. The intestines have a little more than half (0.6) the capacity of the stomach in the dog, whereas in the pig they have 2.3 times the capacity of the stomach, and in the horse 11 times.

The stomach of the dog has a powerful muscle (the pyloric sphincter) which normally does not permit passage of partly digested food until gastric digestion is complete; hence digestion in the stomach is somewhat prolonged. The gastric juice is similar in composition to that of man except that it has a higher content of hydrochloric acid and of pepsin.

Gastric digestion concerns principally proteins, since the amounts of carbohydrates and of fat digested in the stomach are unimportant.

In the dog and in the carnivores in general, digestion of carbohydrates and of fats occurs for the most part only in the small intestine, and absorption of food materials is believed to take place largely from the small intestine. The enzymes necessary for completing the digestion of proteins and for the digestion of fats, starches, and sugars are present in the digestive juices from the pancreas and small intestine, but intestinal digestion is of relatively short duration because of the limited capacity of the small intestine. Apparently the chief functions of the large intestine are to permit absorption of water from the undigested food residue and to serve as a reservoir for the waste materials which constitute the feces.

The digestive canal of the carnivores differs from that of both the omnivores and the herbivores in the relative size and capacity of the different sections as well as in their functions. The differences in the relative capacities of different parts of the gastrointestinal tract of three species representing the herbivores, the omnivores, and the carnivores, respectively, are shown in table 1, which has been adapted from Dukes (*285*, *p. 225*).

The large intestine of the dog is short and of small capacity as compared with that of animals adapted by nature to subsist either wholly or largely on plant foods. The difference extends to function as well as to anatomy. In the dog, the large gut is designed to serve chiefly for storage of a limited and compact bulk of waste material;

it is not suited as a site for the prolonged action of bacterial enzymes, which are considered important factors in the digestion of cellulose and other fibrous constituents of plant foods; and there is probably relatively little, if any, absorption of products of digestion.

TABLE 1.—*Relative capacity of different parts of the gastrointestinal canal in herbivores, omnivores, and carnivores*

Animal and type	Part of canal	Relative capacity	Animal and type	Part of canal	Relative capacity	Animal and type	Part of canal	Relative capacity
		Percent			*Percent*			*Percent*
Horse (herbivore).	Stomach	8.5	Pig (omnivore).	Stomach	29.2	Dog (carvore).	Stomach	62.3
	Small intestine.	30.2		Small intestine.	33.5		Small intestine.	23.3
	Cecum	15.9		Cecum	5.6		Cecum	1.3
	Colon and rectum.	45.4		Colon and rectum	31.7		Colon and rectum.	13.1
	Total	100.0		Total	100.0		Total	100.0

In the herbivorous animals the case is quite otherwise. The large intestine constitutes a large percentage of the total length and total capacity of the canal and serves an important function in the digestion and absorption of food. In the capacious large intestine of the herbivores with simple stomachs, fermentation and solution of the fibrous portion of food take place during a prolonged period of digestion; foods liberated by the solution of the cellulose membranes of plant cells are digested and products of this digestion are absorbed. The large cecum and colon accommodate a bulky diet and provide for the lengthened period required for the digestion of fibrous foods that leave a bulky residue.

The tract of the dog, being relatively short, is best adapted to a concentrated diet that can be digested comparatively quickly and will leave a nonbulky residue. Foods of animal origin are admirably suited to the digestive physiology of the dog because of the ease and completeness with which they are digested as compared with plant foods, which contain considerable amounts of indigestible structural material.

UTILIZATION OF CARBOHYDRATES

The common belief that dogs do not tolerate a diet containing a high percentage of carbohydrate must be based on some other factor than the inability of the dog to digest starch, for it has been clearly shown experimentally (*579, 987*) that dogs can digest large quantities of cornstarch either raw or cooked. Starches in the form of cooked rice fed to mature dogs for a period of 15 days in amounts up to 33 calories a day per pound of body weight—an amount sufficient to satisfy total energy requirements—have been found to be 95-percent digested. Further, the dogs so fed suffered no noticeable ill effects from the starch feeding.

Such results as these lead to the conclusion that if dogs do poorly on high-starch diets it is due to some other factor than any effect of the starch itself. In practice, the unfavorable results obtained are probably due to an imbalance of or deficiency in vitamins, minerals, or proteins, or to the presence of too large amounts of indigestible crude fiber along with the digestible starch and sugar.

In cereals and vegetables the digestible carbohydrates and proteins are contained within cell walls of cellulose and can be acted upon by digestive enzymes only after the cell contents are liberated by the rupture of the enclosing membranes. These cellulose membranes may be ruptured by mechanical means such as grinding, chewing, or application of pressure, by cooking, and by cellulose-splitting enzymes of certain micro-organisms. The delicacy of the cellulose membranes and the ease with which they are broken down vary widely in different plant products and with age, hardness, and the part of the plant used.

The investigations of the digestibility of crude fiber or cellulose by the dog have been reviewed by Mangold (*744*). Some workers have found crude fiber to be almost wholly indigestible, while others have found a considerable degree of digestibility. This variability has been explained by Thomas and Pringsheim (cited by Mangold) as being due to variations in intestinal flora. The dog by nature is without cellulose-splitting bacteria, but under some conditions, after having been fed large amounts of plant foods, he may develop an intestinal flora capable of digesting the more delicate vegetable celluloses.

Mangold (*744*) has quoted some figures obtained by Lössl on the digestibility of fiber of potatoes and of cereals by Fox Terriers. These dogs digested fiber prepared from different sources as follows:

Fiber from—	*Percent digested*
Barley meal	7. 67–33. 53
Potato flakes	15. 37–23. 07
Boiled potatoes	3. 27–86. 83
Rye meal	14. 54–24. 28
Wheat meal	2. 92–87. 52
Rice	25. 24–80. 05

Such wide individual variations with a given carbohydrate can be best explained only on the basis of differences in individual dogs in intestinal flora and in adaptability of the digestive system to an omnivorous diet. Fingerling and Schoeneman (*361*) have suggested that different carbohydrates also differ in the extent to which they are utilized independently of digestibility. Their conclusions were based on results from a group of dogs kept on a maintenance diet of horse meat, which was supplemented by equivalent amounts of several carbohydrates. Different sugars were utilized with equal efficiency but starch they thought was used with greater efficiency than the sugars.

The influence that carbohydrate foods may have on certain phases of mineral metabolism demands attention in a consideration of the place of carbohydrates in the diet of the dog. It has been shown by Mellanby (*778*) that a diet containing just enough calcium and vitamin D to allow normal bone building (calcification) in growing puppies produced rickets when it included a large proportion of cereals. This action of cereals has been explained as the result of a disturbance in calcium absorption due to formation of an insoluble calcium compound in the presence of a high proportion of a compound, phytin, furnished by the cereals. The combination of calcium with phytin (or its sp[illegible]products) apparently occurs, however, only in the absence of fat, since it has been found that the addition of as much as 11 percent of lard or olive oil will counteract the anticalcifying action of the cereals (*727*).

The advantages of including carbohydrates in the diet of the dog are that carbohydrates are a cheap source of energy, both in initial cost and in the work required of the organism for metabolism; and easily digested carbohydrates reduce the break-down of body proteins. Further, some carbohydrate is required for the metabolism of fat.

Since there is ample experimental evidence that the dog has no difficulty in digesting and using starch and sugar for the production of energy, it may be concluded that the presence of a high percentage of these carbohydrates in the diet is innocuous if the diet is otherwise well balanced as to protein, minerals, and vitamins, and contains sufficient fat, and if there is no excessive amount of indigestible and possibly irritating cellulose.

PROPORTIONS OF CARBOHYDRATE AND FAT

Apparently the ratio between fat and carbohydrate may be varied within wide limits as long as the requirements for proteins, minerals, and vitamins are met. Ivy (*578*) has stated that, if the amount of fat is increased gradually, as much as 40 percent of fat in the diet of the dog seems to be well tolerated. Morgan (*814*) reported excellent results from the use over a period of 2 years of a stock ration containing approximately 24 percent of fat. The ration she used later for puppies contained 11 percent of fat. However, in Linton's (*687*) recommendations for an average diet for adult dogs, 5 percent of fat and 70 percent of carbohydrate are suggested. It has already been pointed out that a certain amount of fat in the diet is important in the absorption and utilization of calcium and phosphorus, especially where the percentage of cereals is high and the calcium and vitamin D content no more than just sufficient. In the light of the findings of MacDougall (*727*) in this respect it seems advisable that the amount of fat, especially for the growing dog, should be not less than 11 percent if the proportion of cereal is high, and less than 40 percent in any case; though many rations containing less than 11 percent of fat are apparently adequate for adult dogs. In rations low in fat it is particularly important that a good source of the fat-soluble vitamins be included.

PROTEIN REQUIREMENTS

The view that meat is the essential basis for all successful dog diets receives its chief support from two facts: (1) Meat is in general easily and almost completely digested, leaving little residue; in this respect it is better adapted to the digestive physiology of the dog than the plant products in which the protein may be enclosed in supporting structures of the plant tissues, which are digested with more difficulty and leave a bulky residue. (2) Proteins of animal origin as a class are undoubtedly superior in biological value to those obtained from plants. There remains to be considered, however, the fact that meat is probably less important in the dietary of the dog than popular opinion indicates.

Proteins are required by any animal body (1) for the replacement of the tissue proteins, which are broken down in the metabolic processes involved in body maintenance, and (2) for building new tissues in growth and reproduction. Proteins digested and absorbed in excess of these requirements are for the most part used for the production of energy—either stored as carbohydrate or fat, or expended in heat or work. As sources of energy, however, proteins are less efficient than carbohydrates and fats since they require more energy for their metabolism.

The question whether protein in excess of the two requirements mentioned is advantageous or disadvantageous has long been debated. It is believed by some that the metabolism of excess protein places an unnecessary burden on the body as a whole and on the kidneys in particular. At least direct evidence of definite beneficial effects from any large excess of protein seems to be lacking. However, during the growth period an increase of protein intake above the minimum requirements has a beneficial effect under normal conditions.

Studies of the amount of body protein used by the adult animal in maintaining the metabolic processes essential to life have indicated that the amount of protein required for maintenance is the same for all species per unit of surface area and hence increases with body size. The theoretical requirements for growth, on the other hand, are the amounts of protein actually stored as new tissue, and these decrease in proportion to size of the body as the rate of growth slows down. Likewise the protein requirements for lactation and reproduction are determined by the amounts of protein laid down in milk or deposited in the fetus and the tissues associated with gestation.

A measure of the amounts of protein deposited in the animal body as repaired tissues and as new tissues is not a measure of the amount of food protein that will satisfy these requirements, since food protein varies according to its digestibility and its amino acid make-up. The amino acids are the building blocks of which all proteins are different combinations. Proteins from different sources vary in their value to the body—their biological value—according to their efficiency in supplying all the amino acids required for repair and tissue growth in the proportions needed. Thus there can be no fixed minimum protein requirement for any body function except in terms of a specific food protein or combination of food proteins. No protein has a biological value of 100 percent, but the proteins of whole milk and whole eggs occupy the highest rank, and the proteins of liver and kidney are superior to those of muscle meats, which in turn are superior to those of connective tissue. The plant proteins in general are apt to be deficient in one or more of the essential amino acids. Some of these deficient proteins have been found to maintain adult animals when fed in sufficiently large amounts but not to allow growth in the young animals regardless of the amounts fed. Some of the cereal proteins will support both maintenance and growth, but larger amounts are required to accomplish the same results than in the case of animal proteins.

There is evidence that the biological value of proteins is decreased by the application of heat, particularly very high temperatures. This is an important consideration in estimating the value of protein in commercial dog food.

Lössl (*693*) has reported that good growth of puppies can be obtained when the entire protein in the diet after weaning is supplied by either wheat or rye, but still better growth results from the use of meat protein.

When two proteins of unlike amino acid composition are fed, one may supplement the deficiency of the other, provided, of course, that both proteins are not deficient in the same amino acids. Thus good results can often be obtained from a mixture of proteins each of which is deficient or incomplete. It has been shown that rice bran and corn, tankage and corn, lactalbumin and corn, beef and wheat flour, oatmeal and rice, peas and wheat or rye supplement each other. Kidney, liver, and muscle proteins are more highly effective supplements to cereal proteins than to leguminous proteins. In general, mixtures of plant proteins are improved by the addition of some meat protein.

Casein and dried milk have been utilized as protein sources with entire success by many investigators in meat-free diets for laboratory dogs.

It must be pointed out in any discussion of the relative values of animal and plant proteins that a diet in which proteins are supplied largely by plant products is more likely to be deficient in certain of the B vitamins. The feeding of meat and milk products is the simplest way to supply both the protein and vitamin B requirements of dogs, but it is entirely possible with careful planning that the same results may be obtained with a combination of plant foods and their concentrates.

Little study has been made of the effects in the dog of various levels of protein feeding. Results of observations regarding the amount of protein required for maintenance or for growth are usually expressed in terms of percentage of total calories or as the ratio of calories furnished by protein to calories furnished by fat and carbohydrate.

The total amount of protein required, as has been pointed out above, varies with the kind of protein. Melnick and Cowgill (*782*) used a synthetic ration furnishing 70 calories per kilogram of body weight and fed different kinds of protein to determine the minimum amount of each required to maintain a protein balance in the dog's body. The amounts required, as a percentage of the total calories of the diet, were: Lactalbumin 6.9 percent, serum protein 8.6, casein 9.4, gliadin 21.0 percent. Attention is called to the fact that when the wheat protein gliadin was fed as the sole protein three times as much was required as of the milk protein lactalbumin.

Lössl's (*694*) observations indicated that a nutritive ratio of 1:4 (1 calorie of protein to 4 of carbohydrate and fat) is sufficient for growth in small breeds but that larger breeds utilize to advantage a larger proportion of protein (1 calorie of protein to 2.5 calories of carbohydrate and fat). Morgan (*814*) provided approximately 36.3 calories, of which one-fourth were furnished by protein, per pound of body weight a day to adult dogs, and found it adequate for maintenance; for growing puppies the same proportions were used but approximately three times the amount per pound of body weight. From her studies she has concluded that the optimum protein concentration for all dogs probably lies between 25 and 50 percent of the dry weight of the ration. This protein may be supplied by casein, meats of all kinds, fish, and even cereal proteins.

The protein requirements for reproduction, lactation, and growth are of course much greater than those for maintenance.

Daggs (*247*) has studied the production of milk in the dog as influenced by different kinds of food protein. He has pointed out that relatively high protein diets are beneficial to milk production and that animal proteins are better suited to the synthesis of milk than plant proteins. He used diets constructed according to Cowgill's (*232*) suggestions, which, on a dry-weight basis, contained within a 2- or 3-percent variation for each factor, 25 percent of fat, 40 of carbohydrate, 6 of ash, and 30 of protein. These were supplied to the dogs at the rate of approximately 36 calories per pound of body weight. The protein was supplied from different sources. He concluded that liver was a better source of protein for lactation than eggs or round steak.

Linton has suggested that the average diet for a dog should contain, on a basis of dry weight, 22 percent of protein, 5 of fat, 70 of carbohydrate, 0.5 of fiber, and 2.5 of ash.

ENERGY REQUIREMENTS

The energy requirements of the dog vary widely with size, age, activity, and nutritive condition. It has been shown (*157*) that the maintenance requirements of adult animals for both protein and total energy vary directly with surface area or with the two-thirds to three-fourths power of the body weight. Thus the smaller the dog the greater the maintenance requirements per unit of body weight—assuming energy, external temperature, and nutritive condition to be the same. Young, growing dogs, however, require more food for maintenance, aside from the requirements for growth, than adult dogs. The puppy requires two or three times as much energy-producing food as an adult dog of the same weight.

In addition to maintenance and growth, food must supply the energy used in exercise or work. It is commonly said that the dog should be fed just sufficient to be kept healthy but not fat, since his normal condition is lean. Linton (*687*) has stated that the appetite of the dog cannot be trusted as a guide to the amount of food he requires, and has suggested the use of a table compiled by Dechambre as a suitable guide in estimating the amounts of energy required by adult dogs under different conditions of activity. Table 2 is an adaptation of Dechambre's table as cited by Linton.

TABLE 2.—*Energy requirements of dogs of different weights for maintenance, moderate activity, and great activity*

Weight of dog		Total calories for—			Weight of dog		Total calories for—		
		Maintenance	Moderate activity	Great activity			Maintenance	Moderate activity	Great activity
Kilograms	*Pounds*	*Calories*	*Calories*	*Calories*	*Kilograms*	*Pounds*	*Calories*	*Calories*	*Calories*
5	11	520	680	860	27	59.4	1,550	2,060	2,620
10	22	855	1,140	1,440	40	88	2,020	2,670	3,400
15	33	1,080	1,360	1,680	50	110	2,330	3,085	3,930
20	44	1,265	1,665	2,120	60	132	2,640	3,490	4.450

Contrary to the usual opinion in regard to the unreliability of the dog's appetite as an index of his requirements, Cowgill (*234*) concluded from some experiments that, when all dietary essentials are offered in sufficient quantity and there are no pronounced mental influences operating, dogs will voluntarily adjust their food to their energy needs. The amounts of food consumed by the experimental dogs during periods of nutritive adjustment under the conditions of his experiments were such as to furnish 64 calories per square meter (1.196 square yards) of body surface per hour. This corresponds roughly to 32 to 36 calories per pound of body weight per day for dogs weighing approximately 15½ pounds.

Slightly higher values for maintenance requirements have been reported by Giuliani (*448*), who concluded from his experiments that 22-pound dogs need 40 calories per pound per day, while dogs weighing 110 pounds require only 22 calories.

MINERAL REQUIREMENTS

The mineral requirements of the dog are usually estimated on the basis of requirements established for human nutrition. Arnold and Elvehjem (*35*) have suggested the following amounts as the probable requirements of the adult dog for the 11 minerals that are at present considered essential:

Minimum suggested requirement per pound of body weight per day

Mineral	*Gram*	Mineral	*Gram*
Calcium	0.009	Phosphorus	.018
Sodium chloride	.136	Zinc	.000027
Copper	.000027	Potassium	.036
Iron	.00018		
Magnesium	.0045		*Microgram*
Manganese	.000018	Iodine	.45

Aside from the added salt (sodium chloride) required for rations containing a large proportion of plant products, if natural plant and animal foods are fed, probably the only minerals that require special consideration are calcium and phosphorus. These two make up about 14 percent of the total weight of the bony skeleton, and this 14 percent contains approximately 99 percent of all the calcium and 80 percent of all the phosphorus in the body. It is readily seen that during the growing period when bone is being laid down rapidly there is a greatly increased requirement for these structural elements.

A deficient supply of calcium or phosphorus in the diet of the growing animal, or an interference in their absorption and metabolism, results in malformation and poor development of bones and teeth. Any disturbance in mineral metabolism that results in abnormal calcification of the growing bones is usually termed rickets. This condition may occur as the result of low calcium, low phosphorus, or a deficiency of vitamin D.

Morgan's (*814*) observations have indicated that rickets in dogs is usually of the low-phosphorus type. This is probably related to a faulty utilization of phosphorus rather than to a deficiency in the phosphorus content of the diet, since, when natural foods are used, low-phosphorus diets are less likely to be encountered than low-calcium diets. A ration consisting of a large proportion of muscle meat alone or of muscle meat and cereals is apt to be deficient in calcium. This deficiency may best be compensated for by the addition of bonemeal, ground bone, milk, or calcium phosphate.

VITAMIN REQUIREMENTS

Vitamins have been largely described in the past by the diseases resulting from their absence. It is being recognized more and more that many of the subacute symptoms of general unfitness in dogs may be attributable to an inadequate supply of one or more of these essential food factors.

VITAMIN A

Symptoms of advanced deficiency of vitamin A in dogs are an eye disease with resulting impaired vision, inflammation of the conjunctiva, or mucous membrane which lines the eyelid, and injury to the mucous linings of the body. Less easily recognized symptoms are an apparent lowered resistance to bacterial infection, especially of the upper respiratory tract, retarded growth, and loss of weight.

Diseases due to vitamin A deficiency may be well established while the animal is still gaining in weight. In recent years Mellanby and others have drawn attention to the occurrence of nerve lesions in animals receiving diets deficient in vitamin A. Lack of muscular coordination and paralysis have been observed in dogs, and in many cases degeneration has been demonstrated in the central and peripheral nervous systems. Mellanby has suggested that local infection may be the result of such nerve lesions. Recently Mellanby (*779*) has found that young dogs kept for some months on diets deficient in vitamin A become deaf.

The daily requirements of the dog for vitamin A have been estimated at various figures between 10 and 36 International Units per pound of body weight per day.

Good sources of vitamin A are fish-liver oil, liver, green leaves and other green vegetables, kidney, heart, tomatoes, carrots, cheese, eggs, butter, and milk.

VITAMIN B_1 (THIAMIN)

Vitamin B_1 deficiency in the dog is characterized in its early stages by retarded growth or loss of weight and decreased fertility. There are also loss of appetite and impaired digestion. In advanced stages the animal is paralyzed, there is an accumulation of fluid in the tissues, and death eventually occurs apparently from heart failure.

Vitamin B_1 is partly destroyed by heat at temperatures beyond 100° C. (212° F.), especially in the presence of alkali. Canine daily requirements have been estimated at approximately 3 micrograms of the crystalline vitamin B_1 per pound of body weight.

Important sources of thiamin are yeast, the germ and outer husks of grain, liver, milk, eggs, carrots, and tomatoes.

RIBOFLAVIN

The water-soluble, heat-stable vitamin, riboflavin, of the vitamin B complex, is essential to the dog for growth and for the maintenance of a healthy skin. Street and Cowgill (*1107*) have estimated that 11.3 micrograms a day per pound of body weight will maintain a dog in health for an extended period. Early deficiency symptoms are a variable dermatitis; advanced cases are terminated by death following collapse.

Liver, kidney, yeast, and milk, particularly the whey, are rich sources of riboflavin. This vitamin has a wide distribution in plant as well as in animal foods.

NICOTINIC ACID

This water-soluble, heat-stable factor is widely distributed in animal tissues and occurs in much lower concentrations in plant foods. A deficiency of the factor in the diet of the dog results, in its milder forms, in a loss of appetite and of weight; in acute stages, in the canine disease called blacktongue, followed by death. Sebrell and his associates (*1022*) found that a semiweekly dose of 10 milligrams of nicotinic acid is ample to prevent blacktongue for at least 6 months, the duration of the experiment. A daily allowance of 2.2 milligrams per pound of body weight has been estimated as more than sufficient to supply all requirements.

Good food sources are meat, yeast, fresh or canned milk, eggs, and peanut meal. Experimental work with canine blacktongue, which is analogous to human pellagra, has shown that canned mustard greens, canned turnip greens, and canned spinach are fair sources of nicotinic acid; and 6½ ounces of cooked rabbit meat, 6¾ ounces of smoked pork shoulder (cooked), or 11½ ounces of canned chicken fed daily in 2,400 calories of an otherwise blacktongue-producing diet protected the dog from the disease (*1024*).

VITAMIN C

Although there are some reports of spontaneously occurring cases of scurvy in dogs that have been cured by the feeding of good sources of vitamin C, it is believed that the normal dog can synthesize this vitamin in his own body.

VITAMIN D

An adequate supply of vitamin D is essential for the proper development of bones and teeth. This factor serves as a necessary regulator of the absorption and metabolism of calcium and phosphorus. A deficiency of it results in rickets or osteomalacia (late rickets) even though the diet contains adequate amounts of calcium and phosphorus. In the presence of adequate amounts of calcium and phosphorus, ½ to 1 International Unit per pound of body weight per day is sufficient to protect a dog from rickets. The best sources are sunshine, fish-liver oils, irradiated ergosterol, and egg yolk.

Experiments with very large doses of irradiated ergosterol have shown that a condition of "hypervitaminosis" characterized by the deposition of calcium in the arteries and organs can be induced. The range between the body requirements and the harmful dose is wide, but the possibilities of overdosage should be kept in mind.

Morgan has recommended for young pups and pregnant bitches ½ to 1 tablespoonful per day of cod-liver oil or other vitamin D-containing oil. Adult dogs living out of doors probably do not need extra vitamin D except in pregnancy.

FEEDING DOGS

by S. R. Speelman [1]

HERE are practical directions for the feeding of dogs, including an account of the kinds and quantities of feeds that may be used, preparation of feeds, special feeding at different periods of life, and precautions against unwise feeding.

DOG FEEDS

THE FEEDS commonly used for dogs include meats and other animal products, vegetables, cereals, and commercial mixtures (dog biscuits, meals, and canned foods). Bones are considered an essential food by some, but in reality they are merely mineral supplements, which may not be required in many rations (fig. 1).

Figure 1.—Proper feeding will help to keep this litter of nine puppies healthy and insure their normal growth.

MEATS AND OTHER ANIMAL PRODUCTS

Of the various meats and animal products ordinarily available for feeding, most dog owners prefer beef. For economy, cuts from lean portions of the carcass are favored. Lamb and mutton also are good meats to use when they are properly prepared and not too high in price. Pork is not greatly relished by dogs generally, probably because of its high fat content, and it is seldom fed. The use of poultry of any kind, particularly those portions having bones that splinter easily, is not generally recommended. In some localities fresh horse meat can be purchased from slaughterhouses at a rather low price. This product is economical and usually satisfactory when fed regularly. However, it should not be used unless it comes from a healthy animal that has been slaughtered and handled in a sanitary manner. Horse meat fed in large amounts infrequently may cause diarrhea.

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Fish makes a satisfactory substitute for meat when given occasionally (about once weekly), provided it does not contain harmful bones. Wholesome canned salmon is a preferred fish food and is the one most often used. Salmon is especially valuable and useful when fresh meat cannot be obtained. Canned tuna fish is also suitable, as is cod. Cows' milk and hens' eggs are other valuable meat substitutes. They can be included in the rations of many dogs, particularly young, growing puppies and breeding stock. Skim milk and buttermilk, including the dried forms, are good feeds for some dogs, particularly mature animals, but they are not used as extensively as whole milk.

Methods of feeding meat vary with individual owners and handlers. Some prefer to give all mature animals raw meat, others favor cooking it, and still others feed raw and cooked meats alternately. The last-mentioned plan gives variety, which may be a very important factor when the dogs are finicky eaters, and is often desirable. With ordinary refrigeration, cooked meat usually keeps in good condition longer than raw meat. Unless the cooking is properly done, however, it may remove considerable nutriment from the meat. Meat for dogs may be boiled, roasted, or broiled, but should not be fried. Food losses during cooking may be minimized if the cellular structure in the outer surface of the meat is closed by immersing it in rapidly boiling water for a short time or by searing it. Thereafter, the cooking should proceed slowly, and the broth or meat juices obtained in some instances should not be discarded, because they are valuable for moistening stale bread, dog biscuits, and dry cereal feeds.

Many dog raisers believe that meat feeding should be begun early, when the puppy is approximately 3 weeks old. At this age, about a teaspoonful of finely ground, lean hamburger or well-minced, raw, lean beef (slightly seasoned with salt) may be given most puppies once daily. This allotment should be increased daily thereafter, in order to accustom the puppy to solid food and prepare it for weaning at 6 weeks of age. As with all feeds, the amount of meat to give any young dog varies somewhat and is dependent on a number of factors. Ordinarily, however, a 6-weeks-old weaned puppy of a medium-sized breed may be fed one or two tablespoonfuls of lean meat daily, though it is sometimes advisable to begin with less if the puppy is not used to this food. Puppies of the smaller breeds, of course, need less meat than this and those of the larger breeds more. As the animals grow older the meat allotment should be increased gradually until they are receiving a full allowance, that is, the amount required at maturity. Puppies are placed on full feed ordinarily between the ages of 4 and 12 months, the time being determined principally by the size of the breed to which they belong. Dogs of the small breeds usually are mature when 1 year old, and they may receive a full meat ration at 4 to 6 months of age. In the larger breeds, maturity is attained at 1½ to 2½ years, and in most instances puppies of such breeds may receive full feed when 8 to 12 months old.

The meat given to mature dogs may be fed in large chunks, in medium-sized pieces, or ground. Meat should not be fed on the bone unless the bones are quite large and will not splinter or lodge in the mouth, throat, stomach, or intestinal tract. Most poultry bones splinter, fish bones are sharp and very dangerous, and some lamb and mutton bones lodge badly. None of these or other bones of similar character should ever be used.

In cold climates and in cold weather more meat is usually fed than in warm climates and in hot weather. Moreover, if the dog is closely confined a considerable part of the time and is given little exercise, the meat allowance generally should be less than when the animal is living under outdoor conditions with an unlimited range of activity.

Although the dog is a carnivorous animal and well equipped to digest and assimilate various kinds of meat, some portions of this food are much more valuable than others. Skin, tendons, and cartilage are not digested easily, and it is not advisable to include a large proportion of these in the average ration. Both muscle tissue and glandular organs are required for the best feeding results under general conditions, and they may be given at different times. Of the internal organs, the heart, liver, and tripe are most often used. Muscle tissue keeps fairly well raw with adequate refrigeration, but ordinarily it is necessary to cook glandular organs if they are to be kept for any length of time. Most meat is so thoroughly digested by the dog that little residue is left as fecal matter. Because of this, heavy meat feeding is conducive to constipation.

When salmon is fed as a meat substitute, it usually is given as it comes from the can. The same applies to tuna fish. Other fish may be fed cooked or raw, but they are preferable when cooked and always must be boned thoroughly. Because the protein content of fish is usually somewhat lower than that of good lean meat, it is necessary to feed more fish to obtain the same protein balance. On the average, one-fourth to one-half more fish will be required for this purpose, unless other protein feeds are substituted.

Except for young puppies, cows' milk is ordinarily fed unmodified. The amount of milk different dogs will consume is variable, but except for puppies and some breeding stock, ½ to 1 pint is a normal daily allowance for most small and medium-sized animals, and 1 to 2 quarts should be ample for large dogs. As a matter of economy, skim milk may be substituted for whole milk in some cases. This substitution should not be made for young puppies, however, and it it probable that brood bitches also will do better on whole milk.

Eggs may be given raw with or without milk, or they may be slightly heated in hot water (coddled) before feeding. Occasionally eggs are fed hard-boiled and chopped. When eggs are used in the diet, only one or two should be allowed daily in most instances, except that more may be given to breeding animals, sick or convalescent dogs, and some fast-growing puppies of the large breeds. Eggs are also a valuable feed for conditioning purposes and many exhibitors use them extensively to put their charges in "show shape."

Meat or other animal products are primarily protein-supplying feeds of excellent biological value for growth and development in young animals and for repair of tissues and reproduction in mature stock. For the best feeding results, they must be regularly included in dog rations.

The proportion of animal protein feeds as compared with other feeds in the ration varies in practice, but there is no definite agreement on optimum requirements. In fact, there is a wide diversity of opinion among owners and breeders regarding the correct allotment for average conditions. Under many circumstances, however, it has been found to be good practice to make the ration about 50 percent of meat or meat substitutes (by weight) for most mature dogs, and 65 to 75 percent for young puppies and for pregnant and lactating bitches.

VEGETABLES

The primary functions of vegetables in the dog ration are to furnish vitamins and minerals, supply bulk--act as fillers—and regulate the bowels.

Of the common vegetables, carrots, tomatoes, spinach, onions, and beets are fed rather extensively. Cabbage, turnips, string beans, and certain other green vegetables are sometimes used. Potatoes, fresh corn, shelled beans, and peas are considered undesirable by many dog owners, because some are hard to digest and others are believed to cause disorders of the skin or of the digestive system.

Methods of preparing and feeding vegetables vary somewhat depending on the kind used. Root vegetables have a large amount of indigestible cellulose and must be cooked if it is desired to liberate the starch for feed purposes. Beets and carrots may be fed raw, if the primary purpose is to supply bulk to the ration. Raw tomatoes are particularly suitable because they can be mashed easily and mixed with various other feeds. Thorough mixing of vegetables with the other feeds is important, for otherwise many dogs will refuse to eat them. A satisfactory way of mixing some vegetables with meat is to cook them together as a stew. Meat and vegetables also may be sliced or chopped, mixed, and run through a meat grinder together. Where a variety of vegetables is available, it is well to select the ones that are liked best by the dogs. The extensive use of vegetables having a high fiber content should generally be avoided.

Where feeds of animal origin make up one-half of the ration of mature dogs, vegetables may constitute about one-half of the remainder, or 25 percent of the total. If this results in excessive looseness of the bowels or other digestive disturbances, the amount of vegetables usually should be decreased somewhat. However, those who live in communities where farm livestock feeds can be bought may find that a small quantity of dried beet pulp, added to the dog's ration as a corrective when vegetable feeding causes diarrhea, will give beneficial results. Diarrhea is also checked in many cases by the feeding of small quantities of bonemeal.

CEREALS AND CEREAL PRODUCTS

The various cereal grains and certain cereal products generally are not greatly relished by dogs. Such foods should be used in most cases, nevertheless, since they are valuable in supplying bulk, energy, protein, some vitamins, and minerals. The cereal grains most commonly utilized in some form for dog feeding are corn, rice, oats, wheat, and barley.

Corn is used chiefly as meal to make corn bread—a feed that is best adapted to cold-weather rations and for dogs getting abundant exercise. Corn bread is high in carbohydrates and is not recommended for animals suffering from skin disorders.

Rice is considered a suitable dog feed by some but not by others. To be satisfactory for use, it must be cooked thoroughly and it should be slightly seasoned with salt to increase palatability. Unpolished rice is superior to the common polished type in mineral and vitamin content, but it is also higher in fiber content. Some authorities think cooked rice causes skin troubles similar to eczema, but this may be due to deficiencies in the ration because of an overuse of rice.

Oats are sometimes of value for dogs if ground or rolled. Such feed must be cooked thoroughly. Like corn bread, it is best for active, outdoor dogs and for cold-weather rations. Injudicious use of oatmeal is said to cause certain skin troubles and intestinal disorders.

Except in commercially prepared canned foods, wheat is seldom used as a cooked grain for dog feeding, but various products made from this cereal often find their way into the canine ration. Chief of these are bread, some dry prepared breakfast foods, and dog biscuits and meals. Bread is useful in a variety of forms. Sometimes it is given buttered to tempt the appetites of young puppies and dogs off feed. Dried or toasted bread that is not needed for human use makes a good cereal food for dogs when given in combination with meat broths, soups, or milk. When fed in this way, only enough liquid should be added to moisten the bread. Bread must never be used if it is moldy.

When prepared breakfast foods made from wheat or other cereal grains are fed, they are usually moistened with milk, meat broth, soup, or water. Such foods seem particularly suitable for a light morning meal, and they are being used rather extensively. If a number of dogs are owned, it is often possible to economize on the purchase of dry prepared breakfast foods by getting those portions that have been broken or crushed in the manufacturing process. This food cannot be marketed for human consumption and sells for a relatively low price.

Dog biscuits of various kinds are also generally suitable for supplying the cereal portion of the ration. They may be fed dry, moistened, or mixed with cooked meat and vegetables. These biscuits can be obtained in many sizes and shapes (square, oval, bone-shaped, cubes, pellets, or kibbled—broken into small pieces), and their composition is variable, depending on the specific use for which they are intended. However, practically all of them are high in cereal and low in moisture content, and they consist of various combinations of meat byproducts or meat, cereal grains or products thereof, ground bone, dried-milk products, legume meals, cod-liver oil, fish meal, molasses, salt, yeast, and other substances. Commercially made dog meals are usually similar to dog biscuits in composition, but they are ordinarily not so well adapted to a variety of uses. They are generally fed mixed with water or milk.

Barley is not a very palatable dog feed, but it is used in the cooked form in some commercial mixtures, and barley water and gruel have been found useful for some sick animals and finicky eaters.

In many instances, cereals may constitute approximately 25 percent of the total feed of mature dogs with satisfactory results. Moreover, if it is necessary to reduce the amount of vegetables below the 25-percent allotment previously mentioned, cereals may be used as a substitute for the vegetables removed.

CANNED DOG FEEDS

Most of the feeds already mentioned are well adapted to home preparation and mixing. In addition, there are available a large number of proprietary, ready-to-eat, canned mixtures and canned meat products made expressly for dog feeding. The composition of these mixtures is quite variable, depending on the individual formula and the quality of ingredients used, but in general they consist of cooked combinations of meat byproducts or meat, fish or fish meal, cereals and cereal products, vegetables or vegetable products, ground bone and other mineral matter, and various accessory substances, such as yeast, cod-liver oil, and charcoal. Judging from the analyses of some of these mixtures, they are usually characterized by a high moisture content—65 to 75 percent or more. Moreover, while they are about equal to dry dog biscuits and other dry commercial dog foods in fat content, they are usually much lower in protein, carbohydrate (as nitrogen-free extract), and mineral matter. Most canned mixed foods are intended to be used without supplements. Canned meat products, however, are adapted to mixing with other feed, such as vegetables and cereals.

The use of canned dog feeds has become quite extensive in the United States within recent years, and many such products are now marketed and advertised as complete dog rations. No doubt a considerable part of the growth in popularity of the commercial mixtures is attributable to the fact that these foods generally need no preparation and can be quickly and easily fed. These advantages, however, may at times become disadvantages, particularly when they tend to rob the dog of the necessary balance or variety of diet or when they are uneconomical.

The extent to which canned dog feeds should be used in any given case depends primarily on the needs of the dog and the relative quality, composition, and economy of the canned products compared with home-prepared rations. The labels on most canned dog foods contain data on the kinds and percentages of ingredients in the mixtures, and this information is useful in judging the merits of individual and competitive brands in some instances. Unfortunately, however, the average dog owner cannot usually determine the biological values of the canned products from the tables of contents and statements of analyses; he does not know the optimum percentages of the different nutrients required by dogs of different ages and kinds; he cannot estimate whether the commercial foods are as economical and wholesome as home-prepared rations; nor can he follow the quantitative feeding recommendations some manufacturers give and obtain optimum results. Because of these considerations, it is believed that the economy, practicability, and desirability of using canned dog-feed mixtures extensively may best be determined by individual owners through trial feeding tests. This seems to be particularly essential where no supplementary feeds are used with the commercial mixtures. Moreover, before selecting any canned feed mixture it is well to study the manufacturer's statement of ingredients and analysis, especially the protein, water, fat, and fiber contents; determine if possible by examination whether it contains adulterants or harmful ingredients; and check the net weight and feeding recommendations.

BONES

A great deal may be said regarding the merits and demerits of using bones in dog feeding. Bones are undoubtedly a good source of calcium and phosphorus, they can be digested fairly well by the dog when eaten correctly, and they are valuable for puppies during teething. However, because of the serious or fatal results that may follow the use of some bones, because excessive bone feeding causes constipation, and because bone eating results in abnormal wearing and breaking of the teeth and provokes fights over possession of the bone, it appears that the demerits overbalance the merits. In most instances, therefore, it seems advisable to feed few bones and to rely on other feeds as sources of mineral matter. If these are not adequate, some ground bonemeal can be added to the ration. A specially prepared, steamed bonemeal made for livestock feeding is suitable for this purpose and is available in feed stores in most large communities. Only a small quantity of bonemeal will be needed to supply the calcium and phosphorus requirements of most dogs. The needs of puppies and brood bitches, of course, will be higher than those of other dogs, and allowance for the age and use of the animal should be made when feeding this mineral supplement.

WATER

Regardless of the kinds or quantities of meat, vegetables, cereals, or other feeds used in the ration, it is essential that all dogs except very young puppies be supplied with plenty of fresh, clean, cool drinking water. Some kennels utilize automatic drinking fountains or other water-supplying devices for this purpose. Where fountains are not used, the water in the drinking pans or crocks should be changed several times daily, especially during hot weather. Moreover, it usually is advisable to provide a separate water container for each dog or small group of dogs, and such receptacles must be kept clean.

FEEDING PRACTICES

FEEDING THE BROOD BITCH

When the bitch is neither nursing puppies nor developing unborn young, her feeding program may be about the same as that of other mature dogs. The principal aim should be to keep her in a sound, healthy condition and in medium flesh. One or two meals daily should be sufficient.

When the bitch has been bred and the fetuses are developing, several changes in the regular ration will be necessary. It is particularly essential that the amount of feed be carefully and properly regulated at all stages of pregnancy. For a short time after conception the aim should be to maintain the bitch's weight or increase it very slightly. Two meals daily are ordinarily sufficient for this purpose, and the amount of feed need be increased only slightly over that given before conception. As pregnancy advances, however, the allotment of feed should be gradually raised, and the number of daily feedings increased to three or four. Growth of the embryos is greatest during the last month of pregnancy, and the amount of feed needed during this stage may be about twice that ordinarily given before conception.

Throughout pregnancy the feeds should include liberal amounts of lean meat, eggs, salmon or other fish, milk, and meat broths. Limited allowances of cereals and vegetables also may be included in the ration during most of the period, but not in proportions as great as those given before conception. Some breeders advocate discontinuance of cereal and vegetable feeding during the latter part of the pregnancy period, particularly the last week, in order to prevent overloading of the intestinal tract and undue crowding of the fetuses. About a week before parturition it is usually advisable to make the ration slightly laxative in character. This may be accomplished by giving small daily doses of milk of magnesia or some other mild laxative.

When whelping has taken place, the feeding of the bitch requires especial attention until after weaning time. Feed for the 3 days following parturition should be laxative in character, moderate in quantity, and light in composition. During the first day moderate amounts of warm milk, water, meat broths, or gruels are best. These and other light, sloppy foods should be given the second and third days also. After this the bitch may be changed back gradually to a more solid, substantial ration, such as the one used during pregnancy, except that the amount of vegetables may be reduced considerably or eliminated in order to decrease bulk, facilitate the utilization of more concentrated feeds, and possibly prevent the formation of acid milk, which some authorities believe is induced by vegetable feeding and which produces indigestion in nursing puppies. If the bitch suffers from constipation due to lack of vegetables, this may be corrected by small doses of milk of magnesia.

The quantity of feed given during the nursing period should be regulated to meet the bitch's condition and the demands made on her by the suckling puppies. Feed requirements will naturally increase as the youngsters gain in size, so the bitch's ration must be ample to meet these requirements. In many cases the requirement will be twice that of the nonpregnant, nonlactating bitch. Milk is a particularly valuable food at this time, and liberal amounts of it should be given. The other feeds used must insure adequate protein, mineral matter, and vitamins for proper muscular and skeletal development of the litter. Just prior to weaning time (6 weeks) it may be necessary to reduce the bitch's milk flow. To accomplish this the milk portion of the ration may be gradually diminished or discontinued entirely, and the amounts of the other feeds should be decreased considerably. If the milk flow is not stopped by this procedure, one or two puppies may be allowed to nurse the bitch occasionally for a short period, or she may be partially milked out by hand for several days.

After weaning, the bitch may be returned to her regular ration, provided she is in good condition. If the bitch has lost much weight during the lactation period, she must be fed more than a maintenance ration. The quantity and quality of feed should be sufficient so that she may regain her losses and return to normal condition in about a month's time.

FEEDING THE STUD DOG

In some respects the feeding of stud dogs (breeding males) is similar to that of brood bitches. When not being used for breeding work, the stud dog may be fed about the same as other mature dogs. While in regular service, however, the sire often requires a ration containing more food, particularly feeds that supply protein. When several services are made weekly over an extended period, it may be well to feed the stud dog three times daily, and liberal use should be made of eggs, meat, and milk in his ration. If breeding service is not extensive, two meals daily should be sufficient, and the quantity of feed need be increased very little. Eggs, meat, and milk should be a prominent part of such a ration, however. The aim in feeding any stud dog should be to keep his body weight about uniform and his physical condition excellent. When this is done he will be surer in service and, other things being equal, his puppies should be sound and sturdy.

FEEDING PUPPIES

Generally, the sole feed of puppies for at least the first 3 weeks of their lives is the mother's milk. The first milk is called colostrum, and it is vital that the youngsters receive this. Since puppies are born blind and are unable to walk, it may be necessary to place them at their dam's breasts for the first nursings to insure their getting colostrum. (See article on The Nutrition of Very Young Animals, p. 501.)

After 3 weeks of nursing the puppy may be gradually accustomed to other food. Cows' milk is generally the best food to start with, and later this can be used in combination with stale bread, dry breakfast cereals, and puppy cakes or puppy meal. The milk usually should be fed undiluted, and it should be warmed to approximately body temperature.

In addition to the diet of bread, breakfast cereal, puppy meal or cakes, and milk, at about 3 weeks of age the youngsters should be given their first feeding of meat. The use of this feed in the puppy ration has already been discussed. Raw eggs beaten up in milk, unsweetened evaporated milk, and nongreasy broths made from meats and poured over dry bread or puppy biscuits to moisten them are other valuable feeds for puppies during the preweaning stage.

If puppies have been properly cared for and taught to eat solid and semisolid foods before weaning, no great trouble should be experienced from a feeding standpoint in raising them to maturity. The most important things to remember are to feed them regularly and often, to give feeds that will provide the required bone- and body-building material, to see that all feeds are of good quality and ample quantity, and to keep the feeding and drinking utensils clean (fig. 2).

The young dog is quite similar to the young child in its feeding habits and should be fed a little at a time and often. Immediately after weaning it is usually necessary to feed five or six times daily. Later, young dogs may be fed less frequently, but the amount of food given at each meal must be increased. The schedule of feedings and the amount of food given at each meal are determined by the size of the dog, the stage of maturity, and the kind of feed. In the small breeds, one feeding may be discontinued about every 2½ months until the dog is on a two-meal diet when 1 year old. Dogs of the larger breeds cannot have their feeding schedules changed so often, and there may be intervals of 3 to 4 months between changes. At no time during the growing period should puppies be allowed access to food at will. Rather, the animal should be given about 10 minutes in which to clean up each meal, and at the end of this time the uneaten portion should be removed. By following this practice puppies are kept "on feed," and they do not get food that is spoiled or dirty. When a number of puppies are fed, it generally is best to give them individual feed pans. In this way each dog will be sure to get the desired amount and kind of food, and the weaker ones will not be bullied and robbed by their stronger mates.

Throughout the growing period the feeds should include liberal amounts of lean meat, milk, eggs, salmon or other fish, and meat broths. Cereals and vegetables may be included also in limited quantities, but they should not constitute a very large part of the ration during the early stages of puppyhood, and they should never be used in proportions as great as those given to mature animals.

In addition to the regular feed given a puppy, many dog owners have found it advisable to include a small quantity of cod-liver oil in the

Figure 2.—Puppies do not always show such good manners as this, but individual feed pans, kept scrupulously clean, and regular meal times will help to keep them healthy and happy.

daily ration. Beginning with a few drops at the start, the amount may be increased gradually up to one or more teaspoonfuls daily, depending on the needs of the animal. The use of cod-liver oil is generally most necessary during winter months and when the dogs are not allowed to run in the open where there is plenty of sunshine. The feeding of cod-liver oil is also indicated where there are tendencies to develop rickets. Usually the cod-liver oil should be mixed with the food to simplify feeding it.

QUANTITIES OF FEED REQUIRED

The quantities of feed required daily by dogs are influenced and determined by a number of factors: The age, size, individuality, and physical condition of the animal; the kind, quality, character, and proportions of the various feeds in the ration; the climate, environment, and methods of management; and the type and amount of work done, or the degree of exercise. Of these considerations, the age and size of the dog and the kind and amount of work are particularly important in determining feed requirements.

The influence of age on feed requirements is especially noticeable during the first 6 months of life, and the quantity of nutrients necessary to care properly for rapid muscular and skeletal growth, metabolism, and other vital functions is proportionately high. During this period the amount of feed required per pound of body weight of the puppy may be two to three times that of mature dogs of the same type or breed kept under comparable conditions. Moreover, the quantities of feed are greatest per pound of body weight at the youngest ages and decline gradually until maturity. Increases in body weight and size usually vary in the same manner.

At all ages, size and weight are important considerations in determining the amount of feed required. Small dogs naturally need less feed than large ones, but the requirements per pound of body weight are considerably greater for the small dog, whether it is a puppy or a mature animal. Such differences are particularly marked in the case of mature dogs that vary greatly in size—for example, those under 10 pounds compared with those of 150 to 225 pounds. Table 1 gives the approximate daily feed requirements (exclusive of drinking water) of mature dogs of various weights kept under average conditions and exercising moderately. This computation is based on home-mixed rations consisting of meat, fish, eggs, milk, vegetables, and cereals of good quality. The proportions are approximately 50 percent of animal protein foods, 25 percent of vegetables, and 25 percent of cereals.

TABLE 1.—*Approximate quantities of feed required daily by mature dogs*

Body weight (pounds)	Total feed (wet basis)	Feed per pound of body weight	Body weight (pounds)	Total feed (wet basis)	Feed per pound of body weight
	Pounds	*Ounces*		*Pounds*	*Ounces*
1	⅛	2.00	75	3¼	0.70
10	¾	1.20	100	4	.64
25	1½	.96	150	5¼	.56
50	2½	.80	225	7	.50

The influence of reproduction and lactation on the feed requirements of breeding stock has been noted. Ordinary physical activity (work and exercise) is also important in determining feed requirements, and careful consideration should be given this matter when planning rations. To determine the amount of feed that will give best results for dogs that are very inactive or those doing hard work, it is advisable to try rations containing different quantities and combinations of nutrients. For the very inactive dog, the allotment probably can be reduced 25 to 35 percent below the recommendations given in table 1. For hard-working animals, however, an increase of 25 percent or more may be needed (fig. 3).

Ordinarily, the effects of the quality, kind, character, and proportions of nutrients on quantitative requirements are most significant when very dry feeds or those of low energy and biological value are used extensively. When the moisture content of the ration is low, as when dry foods are used to any great extent, considerably smaller quantities of feed may be needed. If the energy value or the protein content of the food is low, or the proteins are of poor quality, more feed should be given. Where radical departures are made from the recommendations already given for the proportions of animal protein foods, vegetables, and cereals, the total quantity of feed will probably have to be changed also, and in fact the ration may not give satisfactory results. Particularly is this true in the case of puppies and brood bitches.

FEED ECONOMIES

By careful planning and the adoption of correct feeding practices it is often possible to effect economies in rations without sacrificing either the efficiency of the feed or the health of the dog.

Figure 3.—Hard-working dogs require more feed than idle animals.

Where one dog of small size is kept, it may be practical to obtain a considerable portion of the food from table scraps, particularly stale bread, some vegetables, cereals, and meats, sour milk, etc. In the utilization of such food it is of course necessary to exclude fried and highly seasoned meats, dangerous bones, unsuitable vegetables and cereal products, and all other substances that have been mentioned here as undesirable. Moreover, the frequent tendency and temptation to use the dog as a scavenger or a second garbage pail is most certainly to be avoided.

When more than one dog is fed, considerable economies cannot usually be obtained by using table left-overs, but they may sometimes be effected by purchasing feed in quantities and by obtaining stale bread, cracked eggs, good meat scraps, broken cereals, and similar products that cannot be marketed for human use but are sound, wholesome, and entirely satisfactory for dogs. Also, in the purchase of meats it is not necessary to get the prime or top grades. In fact, the medium grades of meat are not only lower in price per pound but also a better feed for dogs, because such meat contains a higher proportion of lean and therefore a greater percentage of protein.

Feed economies may also be effected by studying the habits, preferences, and idiosyncrasies of each dog. Although this article has attempted to outline general rules of dog feeding, the matter of individuality is a factor that only the owner or feeder is in a position to observe and handle, and he must determine the correct proportions and kinds of feed that will give optimum results under specific conditions. Once these facts have been established, there should be little food waste.

FEED DEFICIENCIES

When dogs are given adequate rations containing a variety of feeds of animal and plant origin such as have been suggested, there should be no serious nutritional deficiencies requiring the use of special products to supply vitamins, mineral matter, or other nutrients. There are instances, of course, as in the case of fast-growing puppies of the large breeds or bitches nursing large litters, where vitamin and mineral supplements may be beneficial. However, such products should not be employed indiscriminately, nor should dogs be dosed with proprietary articles to cure or correct conditions that are largely imaginary or that do not result from faulty nutrition. If the dog does not thrive on a ration of sound, wholesome foods, a veterinarian should be consulted.

FEEDING SUGGESTIONS IN BRIEF

Many dogs are overfed. Others do not receive adequate rations. Both extremes should be avoided, but particularly overfeeding.

Overfeeding, coupled with lack of exercise, usually produces excessive body weight and laziness, and it may induce sickness and impotency.

Prolonged undernourishment causes loss of weight, listlessness, sickness, and death.

The aim in feeding puppies should be to keep them growing steadily and uniformly, but not too fast.

It is usually advisable to keep puppies just a trifle hungry. This may be accomplished by feeding a little at a time and often.

An adequate ration will keep most mature dogs at a uniform body weight and in a lean, thrifty condition. This is a very useful guide in determining the correct amounts to feed.

Generally, the use of too hot, too cold, highly seasoned, fried, or sweet foods should be avoided. However, most cooked foods should be slightly seasoned with salt.

The appetite of the dog cannot usually be taken as a guide to its feed requirements. Many dogs will overeat if given the opportunity.

The axiom, "One man's meat is another man's poison," is applicable to dogs also. Feeds that are not tolerated by the dog or those that cause digestive and other disturbances should not be used.

The use of moldy, spoiled, or rotten feed is never a good practice.

The excessive use of feeds of low energy content and low biological values will often result in poor condition and may cause loss of weight and paunchiness.

Economies in rations and feeding practices are desirable, but not if they are obtained at the expense of the dog's health and efficiency.

All feeding and drinking utensils must be kept scrupulously clean.

The crude-fiber content of the ration should be kept at a low level, usually below 2 percent. This is ordinarily accomplished by a ration that contains a good proportion of feeds of animal origin.

It is usually desirable to reduce the feed allotment during hot weather.

Dogs should be fed at regular intervals, and the best results generally may be expected when regular feeding is accompanied by regular exercise.

Most dogs do not thrive on a ration containing large amounts of sloppy feeds, and excessive bulk is particularly to be avoided in the feed of hard-working dogs, puppies, and pregnant and lactating bitches.

Hard-working dogs and those getting abundant exercise require less vegetable matter in the ration than idle, nonworking animals.

Maintenance of a weekly weight chart is useful, and it is especially advisable where numbers of dogs are being fed.

If the ration is known to be adequate and the dog is losing weight or is not in good condition, the presence of internal parasites is to be suspected.

It is not usually advisable to feed either directly before or directly after working or exercising the dog. Rather, allow the dog an hour of rest before feeding.

The feed requirements of puppies, working dogs, and brood bitches are often quite high. The use of feeds of high energy and biological value—preferably feeds of animal origin—is particularly valuable for such stock.

Sometimes dogs go "off feed" for a day or two. When this occurs they should not be forced to eat, but if they do not voluntarily return to feed within 2 days, a veterinarian should be consulted.

In general, sick and convalescent dogs need easily digested, readily assimilable feed, but no specific recommendations that will apply to various diseases and conditions can be given.

Although the dog may show no immediate or outward signs of the effects of improper feeding or malnutrition, this does not prove that no harm is done.

A good coat, bright clear eyes, and an abundance of pep are reliable indications that the ration is adequate.

Mature dogs are usually fed twice daily, a light meal in the morning and a heavier meal in the afternoon or evening. However, if the dog is used for watch or guard purposes at night, it is best to give the heavier meal in the morning.

The ultimate aim of feeding should be to obtain longevity and a constant state of good health.

NUTRITION OF FUR ANIMALS

by Charles E. Kellogg [1]

SILVER FOXES, minks, and rabbits are now being raised as part-time enterprises on a considerable number of farms, and some producers are in the business on a large scale. There is also some interest in the raising of martens and fishers. Here is a summary of the scientific work—not yet very extensive—that has been done on the feeding of of these animals, with special emphasis on its practical application.

THE ONLY FUR ANIMALS that are now being raised commercially to any great extent are silver foxes and minks. Martens and fishers also have commercial possibilities if satisfactory reproduction can be obtained in captivity. Attempts have been made at one time or another, largely through the efforts of propagandists, to "ranch-raise" skunks, badgers, raccoons, beavers, and muskrats for their fur, but the undertakings were not profitable because the cost of feeding and other costs of production exceeded the market quotations on similar wild-caught skins. A striking mutation may develop in some of these species, however, which will produce an animal with new characteristics that will make production in captivity remunerative.

Natural selection in the wild, where matings are promiscuous, fosters the survival of those animals best fitted to live under rigorous conditions. The survival of fur animals in captivity, where matings can be controlled, is dependent upon their ability to produce beautiful pelts economically under more or less pampered conditions, rather than upon adaptation to rigorous competitive living. The profitable type is the docile, tractable, easily kept animal that responds to care without putting on excess fat and becoming sluggish and nonproductive. Economy of handling in captivity does not permit the retention of animals that require considerable exercise to be prolific. Elimination of the undesirable types is taking place on the more progressive ranches, though most emphasis in selection has thus far been placed on color and density of fur, prolificacy, and other factors that have a greater immediate bearing on commercial value.

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The abundant available information on human and domestic-livestock nutrition provides some foundation on which to develop suitable rations for fur animals in captivity. But after all, foxes, minks, martens, and fishers are carnivorous animals recently taken from the wild, and much remains to be learned about their food requirements. This fact has caused governmental authorities in this and other countries to establish experimental units for specific research on the nutrition of fur animals that give promise of profitable commercial production.

RESEARCH ON FUR ANIMALS LIMITED

Though numerous experiment stations in the United States are studying the nutrition of domestic livestock, only one Federal experiment station, three State agricultural experiment stations (Oregon, Wisconsin, New York (Cornell)), and one Territorial station, are doing nutritional research work with fur animals. The studies at all the State stations were started within the past 2 years, and those at the Territorial station, at Juneau, Alaska, were initiated in the fall of 1938. Cornell University conducted a metabolism study with minks for 1 year (1936), and in the fall of 1938 began research work on the nutritive requirements for growth, fur production, and reproduction of foxes and minks in cooperation with the Bureau of Biological Survey.

The United States Fur Animal Experiment Station at Saratoga Springs, N. Y., had been located from 1916 to 1923 at Keeseville, N. Y. Small numbers of silver, red, cross, and blue foxes, martens, minks, fishers, badgers, skunks, and domestic rabbits have been maintained at this station at different times. All species were eliminated by 1938 except silver foxes, minks, and martens. Testing various types of equipment, pens, and kennels, checking trial feed formulas, and perfecting methods of handling and management were essential in the earlier years before controlled experimental work could be inaugurated. Satisfactory control of fur-animal diseases and parasitic infestations also had to be established. All of these studies provided fundamental information of distinct value to fur farming.

SILVER FOXES

CHARACTERISTICS AND BREEDING HABITS

The beauty of the silver fox fur is partly due to the fact that foxes have two types of hair—fine underfur and longer, coarser top hair called guard hair. Many of the guard hairs have white bands of varying widths toward the tips; these hairs are not entirely white or even white-tipped, as is commonly supposed. The silver-black fox is a mutation of the red fox in which the black pigment has replaced the red. The white bands appear silver on the black background. The degree of silver is determined by the width of the white band and the frequency of these banded hairs over the entire body of the fox. The present popular bright silver pelts have wide bands of clear white on most of the guard hairs over the entire body except the neck region. The black tips of the guard hair overlying or veiling the clear white band accentuate the silvery appearance. The clearness of the colors, though largely due to selective breeding, is affected by feeds and by systems of management.

The mutations to black occur in wild red foxes in Alaska as well as in the eastern part of Canada. The silver fox developed from the eastern strain, most common on farms at the present time, is known as the eastern standard type. The average weight of males of this type at maturity is 12 to 15 pounds and that of the females 10 to 12 pounds, when in good thrifty condition. Matings occur from middle January to middle March. Pair-mating 1 male, technically known as a dog, and 1 female, or vixen, in the same pen is followed by the larger ranchers. Recently some of the small ranchers have been mating their foxes polygamously, that is, using 1 dog to breed as many as 10 vixens.

Not more than one litter is produced each year after a gestation period of 52 days. A few litters of 9 or 10 are obtained, but an average production of 3½ to 4 young for every vixen is considered satisfactory, and of course some of the vixens do not produce each year. Though the ranchers with large numbers of animals leave the pups with the parents until September, others wean them at about 8 weeks old, when they weigh about 4 pounds, male pups being about a quarter of a pound heavier than females at this time. Smith (*1067, p. 36*)[2] found the body length of male pups to be 16¼ inches at this age and that of females 15½ inches. The young foxes attain the weight of mature animals when about 7 months old. The pelts are taken in November or December when the animal is 9 to 10 months old, depending on climatic conditions. Fox pups will breed the following spring when they are about 1 year old.

The mature animals begin shedding their fur the early part of June. Shedding is usually complete by August, depending on climatic conditions and general health of the animal. A full growth of new fur must develop by pelting time in early winter. Though it is generally believed that pups shed their fur the process is quite gradual.

Foxes are productive until 9 to 10 years of age but they are seldom kept that long. At present the higher prices prevailing for pale silver skins are inducing fox breeders to replace the darker mature breeding animals with lighter-silvered pups.

MANAGEMENT PRACTICES

At the larger ranches the breeding pairs of foxes are still provided with ground-floor pens 20 by 40 feet to about 40 feet square with a 2-foot wire overhang to prevent escape. At other ranches the males and females are maintained in separate pens with raised wire floors (fig. 1, *C*), for sanitation and control of parasites, 6 to 8 feet wide and ranging from 16 to 30 feet long and 4 to 6 feet high. A wire netting covers the top of this entire pen. The specialized larger ranches about October 1 transfer the animals to be pelted into "furring runs" (fig. 1, *A*). A furring run may be a fenced area of 25 acres of dense woods, which is sufficiently large for about 500 animals. Usually no shelter is provided. Other fox farmers have built raised wire-floored furring sheds large enough for confining 50 to 100 foxes during the day; these animals may be released during the night into a large fenced outdoor runway.

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[2] Italic numbers in parentheses refer to Literature Cited, p. 1075.

On other farms the sheds are divided into compartments for 2 to 4 animals each. Protecting the foxes from sunlight tends to produce clearer-colored pelts free from a rusty or tinged appearance.

The largest ranches have as many as 8,000 vixens and employ a large crew of men. Smaller enterprises may have as few as half a dozen vixens being taken care of at odd moments. The majority of the fox farms in the United States are part-time enterprises.

Feeds and Feeding Practices

Though foxes in the wild are largely carnivorous they do eat berries and other fruits, some vegetation, the contents of the digestive tracts of rodents, and occasionally insects. When foxes were first confined, there was considerable difficulty in feeding them properly. By persistent trials with various kinds of feeds and combinations of feeds a variety of fairly suitable rations have been developed by the fox farmers. Of course, continuous selective matings have developed a type of fox better adapted to the changed conditions.

Meat—raw, desiccated (dried and ground), or both raw and desiccated—constitutes 40 to 80 percent of the entire ration, depending on the season of the year and the method of figuring. Discarded farm horses, because of relative cheapness, provide most of the raw meat. Usually the carcasses are boned and the meat and bones are ground separately to facilitate storing in frozen slabs. Grinding also effects thorough mixing of all ingredients, so that the fox cannot pick out certain choice morsels. The use of large quantities of raw meat has necessitated the installation of freezing equipment on many farms where a large number of horses are slaughtered before winter sets in. Some farms are close to cities where refrigeration is available at moderate cost. Internal organs and blood are always used.

The cheaper cuts of beef, packing-house trimmings, internal organs, and parts considered unfit for human consumption, such as udders and lungs, are widely used. Relative cost is the primary incentive for choice. Large numbers of jack rabbits are used in the Middle West. In some sections of the country some of the meat is replaced with fresh fish, canned fish, or fish meal. The remainder of the ration is then made up of an assortment of waste products from the manufacture of cereals, one or more of the vegetable proteins such as soybean meal, milk (liquid or dried), dried fruits, green vegetables, ground green bone, and certain vitamin concentrates. The kind and quantity of these various ingredients are largely determined by the results obtained by successful nearby fox farmers. Their variety demonstrates the adaptability of the fox to different kinds of feeds.

Water or liquid milk usually is added to bring the feed to a "hamburger" consistency, which apparently is most palatable to the foxes. Commercial feed companies are selling great quantities of mixed feeds in meal form to use in conjunction with the raw meat, or in cube form to be fed dry as a complete feed during the summer and fall months.

At first the feed was simply thrown over the pen fence onto the ground, but the occurrence of parasitic infestation and disease led to the use of feed pans that were washed and scalded each day. At present many foxes are fed in a wooden or metal trough attached to the side wall of the fence in such a way that the fox can work the

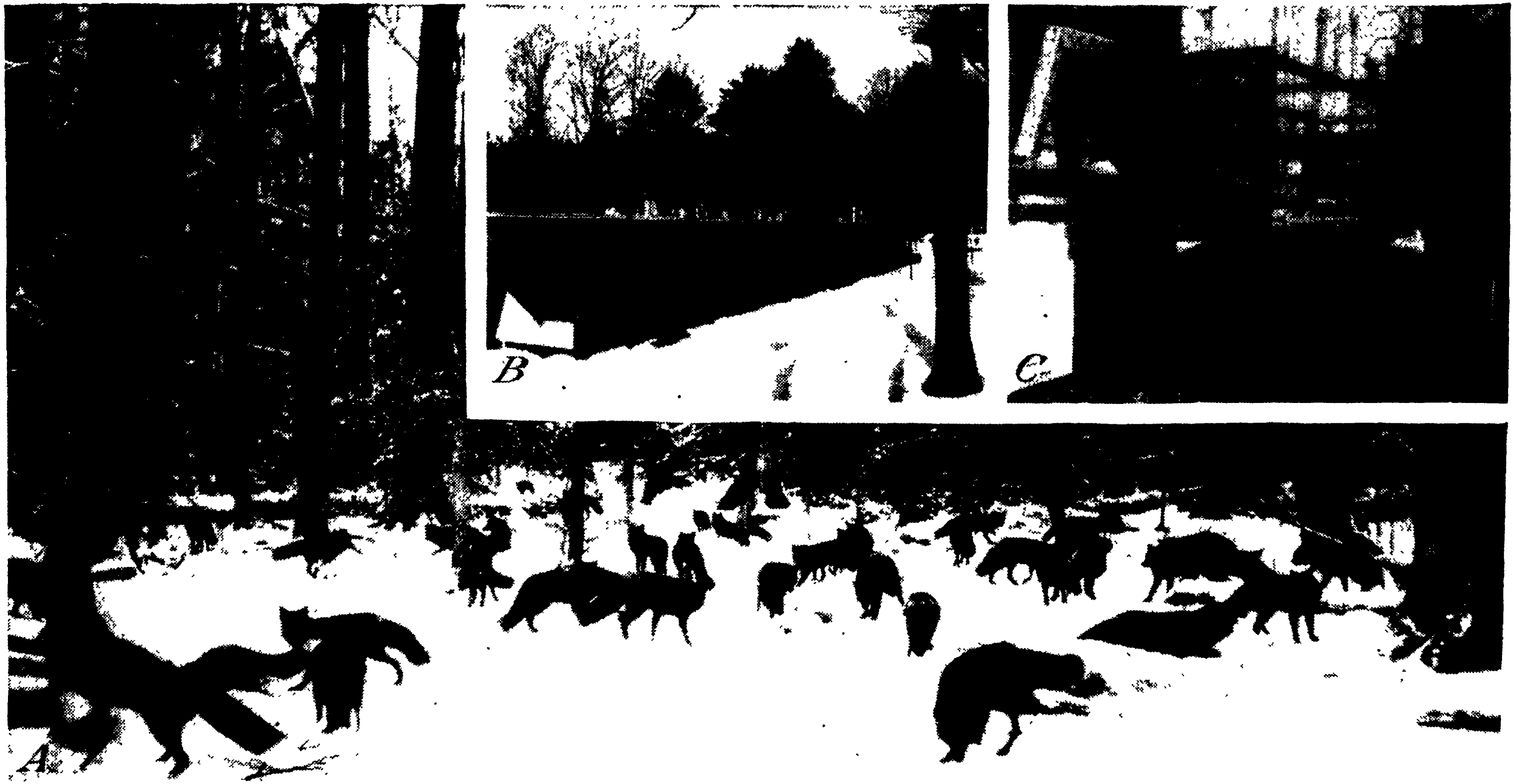

Figure 1.—*A*, Foxes on a furring range just before feeding time. (Courtesy Fromm Bros.) *B*, One of the mink colony houses at the United States Fur Animal Experiment Station, Saratoga Springs, N. Y. Cans for supplying water in winter are outside the houses. Feed is supplied on the wire netting covering the nest boxes, which are inside the shed. *C*, Silver fox in raised wire-floored pen at the experiment station. Note the feeder attached to the side of the pen. The feed is placed from the outside against the large horizontal spikes across the opening.

feed through the wire as desired. A narrow platform or ledge of the trough extends inside the pen to prevent the feed from being unduly wasted. Vixens suckling pups are still fed in pans washed and scalded each day.

Mature animals during the summer, fall, and early winter are usually restricted to about 0.9 pound of mixed ration (hamburger consistency) once daily, in the evening, or an equivalent amount on dry basis of commercial feed in cube form. Weaned pups are fed similarly during the fall and summer, except that the ration is full fed up to 1¼ pounds daily. Full feeding twice daily of a richer ration is given after the vixen gives birth to her whelps.

REDUCTION OF FEED COSTS NECESSARY

The increase in the number of silver fox pelts produced in the United States as well as in other countries has so reduced the sale price of the skins and raised the cost of feeds commonly used for foxes that the profits are becoming continually smaller or entirely disappearing. Buyers are demanding better pelts for less money. The use of expensive feeds and extravagant methods of feeding that might be economically permissible when large profits are made is impossible on the present close margin of profit. The search is ever for cheaper satisfactory substitutes, such as desiccated meats and plant proteins for raw meat, and raw or specially processed cereals for breakfast-food wastes. To determine the kind and proportions of these cheaper feed substitutes that will still produce a silver fox skin that is large, durable, clear in color, densely furred, and lustrous is one of the chief problems of the industry. Naturally, the effect of such cheaper feeding during the important pregnancy and lactation periods of the vixen and during growth of the young is of tremendous importance.

Unfortunately the fox-farming industry has developed at a period when vitamin and mineral supplements are the vogue in both human and livestock nutrition, with the result that fox farmers have been flooded with propaganda urging the inclusion of an overabundance of these expensive ingredients. The kind, the amount, and the time of year, if at all, to include these special ingredients need to be determined under controlled conditions of management and with equalized groups of animals. Too much of the feeding information available to fox farmers at the present time is based upon tests with too few animals in unequalized groups and conducted by organizations that are not altogether impartial. Some feed companies, taking advantage of already-established good management practices and excellent breeding stock, have intimated that such successful results are due primarily to the use of their product.

NUTRITIVE REQUIREMENTS OF SILVER FOXES

With worm-free foxes, the total caloric maintenance requirement for mature animals as determined by Smith (*1067*) is between 95 and 100 calories per kilogram of live weight, based on the minimum summer weight, and there is little variation in that requirement during the entire year. He states that caloric requirements of foxes are dependent upon body area rather than live weight, and a daily requirement of 360 to 550 calories is given for foxes ranging from 24 to 27 inches in body length. A table is given showing the caloric requirements for suckling and weaned pups of various ages. It was found that a definite quantity of food produced a definite gain in the weight of healthy pups, the quantity being calculated by its caloric value. After 5 months of age the food requirements increased to 750 calories daily, approximately one and one-half times the quantity for the average large-sized fox. Slight underfeeding for 1 week did not materially affect the growth of the pups, but continuous excessive feeding led to disastrous results.

Smith (*1067, p. 7*) states that the total daily protein requirement for a small fox should not exceed 0.06 pound during the summer, to 0.085 pound in early winter, and these quantities should be graduated according to size of fox up to 0.14 pound for an unusually large animal. He believes that excess protein tends to develop a coarse, streaky, open underfur at the expense of the guard hair and that a smaller quantity will not permit proper growth either of guard hair or of underfur.

The summer rations fed foxes at the United States Fur Animal Experiment Station, according to average chemical analysis of various ingredients show on a dry-matter basis approximately 42 percent of protein (about two-thirds from animal and fish sources), 6.4 of fat, 37 of nitrogen-free extract (the more soluble carbohydrates and more soluble parts of the celluloses and pentosans), and 9.7 percent of minerals. On a basis of 1 pound of feed per day (including moisture and added water) the foxes were furnished about 0.16 pound of protein, 0.023 of fat, 0.13 of nitrogen-free extract, and 0.034 pound of minerals daily. How much of these various nutrients was utilized by the fox is not known, since digestion trials have not been run on foxes.

Vitamin A Studies

The specific vitamin requirements of foxes have never been determined, but some basic research on the question of storage of vitamin A in the livers of foxes was done by Holmes and others (*529*) by assaying livers taken at pelting time from 10 ranch-raised foxes. These foxes had been fed a ration containing 25 to 30 percent of commercial feed and 70 to 75 percent of horse meat. The livers constituted 3.53 percent of the live weight of the foxes, carried an average fat content of 2.25 percent of their own weight, and contained an average of 2.5 Lovibond Blue units [3] of vitamin A per gram of liver. Unfortunately, the quality of fur was not studied, nor was the presence or absence of urinary calculi (gallstones) determined. The formation of urinary calculi is considered by some to be caused by vitamin A deficiency.

The storage of vitamin A in the livers of foxes was given further study by the same authors (1938–39) in cooperation with the Bureau of Biological Survey.[4] The livers of 41 foxes of various ages fed on three different experimental rations during the summer and fall were assayed for vitamin A by the above-mentioned method. A careful post mortem revealed no calculi, and internal parasites were present in only a few individuals. The internal organs generally were in normal condition and there were no indications of definite vitamin

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[3] The Lovibond Blue unit is a measure of the vitamin A content by the antimony trichloride colorimetric method.

[4] Manuscript in preparation for publication.

A deficiency, but some of them may have been on the border line. All animals were fed rations similar except for the test ingredients as listed in table 1. Dry mixture No. 7 (p. 880) constituted 25 percent of each ration; equal parts of tomatoes and carrots, 5 percent; and ground green horse bone, 5 percent. Added water comprised 24 percent of the ration containing the raw meat, and 53 percent of those having the dessicated (dried) products. No vitamin A supplements were supplied in any of the rations.

Table 1.—*Comparative data on vitamin A content of livers of 41 experimental silver foxes, 15 wild red foxes, and 4 wild gray foxes*

Number, age, and source of animals	Test ingredients in ration		Liver weight in proportion to body weight	Liver fat	Lovibond Blue units of vitamin A per gram of liver		Weight of green pelt in proportion to body weight
	Material	Quantity			Range	Average	
		Percent	*Percent*	*Percent*	*Units*	*Units*	*Percent*
15 mature silver foxes [1]	Beef meal Liver meal	9.6 2.4	2.7	2.90	1.3 to 4.7	3.2	17.8
8 silver fox pups [1]	Raw meat Bonemeal	[2] 40.0 1.0	2.8	2.60	7.1 to 10.9	8.8	17.8
10 silver fox pups [1]	Beef meal Liver meal	9.6 2.4	3.1	2.69	1.8 to 4.0	3.2	18.3
8 silver fox pups [1]	Beef meal Soybean meal Liver meal	4.8 4.8 2.4	3.0	2.74	1.3 to 8.8	3.7	18.2
15 wild red foxes from Connecticut, Maryland, New York, and Massachusetts.	Unknown			5.43	2.3 to 2,040.1	613.8	
4 wild gray foxes from Connecticut.	do			5.29	180.1 to 1,267.0	348.2	

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[1] From the U. S. Fur Animal Experiment Station, Saratoga Springs, N. Y.

[2] 25 percent of red muscle meat and 75 percent of viscera (50 percent of tripe, 25 percent of udders, and 25 percent of lungs).

The groups of animals receiving the rations containing the desiccated products showed an average of 3.2 to 3.7 Lovibond Blue units of vitamin A per gram of liver. The pups receiving the raw-meat ration showed on an average 8.8 such units, or over twice as much as that in the livers of the other groups. In contrast to this relatively small amount of vitamin A reserve in the livers of the ranch silver foxes it was found that wild red foxes from four States averaged 613.8 units of vitamin A and four gray foxes, 348.2 units. Because such a relatively large amount of vitamin A is found in the livers of wild foxes no inference should be drawn that this amount is necessary for their well-being or for that of the silver fox in captivity.

Apparently there is no correlation between the larger vitamin A content of the livers at these levels and the quality of silver fox pelts as determined by critical examination by experts in the fur trade. Skins grouped together for the general criticism were from animals with both the lower and higher vitamin A content in their livers. The skin from an animal the liver of which contained 10.9 Lovibond Blue units per gram, was given this general description—"very short in underfur and very short in guard hair, poor coverage, poor pelt." Two pelts from other animals having 2.4 and 2.7 Lovibond Blue units per gram of liver were described as "full growth of fur, well covered, enough under fur and guard hair, quality is there."

It should be kept in mind that the above information concerns only animals to be pelted. The vitamin A requirements during pregnancy and lactation and during the growth of the pups should be much higher than that needed for proper developing of the pelt.

Vitamin B Deficiency Reported

In the search for cheaper feed, fresh fish in various proportions has been used to replace the raw-meat part of the ration. The results obtained have not been consistent.

R. G. Green of the University of Minnesota attributes the disease known as Chastek paralysis to vitamin B deficiency. He reported in July 1938 (*438*) on nine major outbreaks of this disease in foxes in various sections of the country over a period of years. These began, he states, shortly after the addition of fresh raw fish to the diet. "Lesions identical with those found in the brains of foxes with Chastek paralysis have been described in the brains of dogs with vitamin B–1 deficiency." Though this disease occurred most frequently during the first 3 months of the year it has been produced experimentally by Dr. Green in summer. Production of Chastek paralysis by the use of fish as feed, he says, is in no way related to fish spoilage, and any kind of fish may cause it. The feeding of fresh fish, which lack this vitamin, produces the disease by cutting "down the amount of vitamin B in the diet simply by replacement of other foods which contain it" and by raising "the requirement of the fox for this vitamin" because of the oil contained in the fish. He further states that some fox rations are so near the minimum border line of vitamin B requirements that a small quantity of fresh fish will cause trouble.

The fox farmers of eastern Canada, on the other hand, are feeding fish as one-third to one-half of the meat part of the ration with satisfactory results. In that region, however, fish feeding is largely discontinued after September 1 because it is believed to have a detrimental effect on the quality of the pelt. Research work on the kind of fish to use and amount to feed without harmful results to the health of the animal and the quality of the fur is urgently needed. Fish is a fairly cheap food for fur-animal feeding.

STUDIES AT THE UNITED STATES FUR ANIMAL EXPERIMENT STATION

Research Procedure

At the fur animal experiment station animals are equalized into groups according to such standards as age, sex, ancestry, and previous feeding and breeding records. Even though the returns come from the pelts, live weights are taken to ascertain responses to various rations. The resulting information is supplemented with observations and tests on fur growth, quality, and other factors.

Sufficient water is added to all rations to make their total water content similar, which is an indirect way of bringing the rations to the same dry-matter basis. The addition of water is necessary to give the feed hamburger consistency. Even when a ration contains 40 percent of raw meat, approximately 22 percent of water must be added because of the inclusion of dry cereals and other desiccated products. Bringing all rations to the same water content makes possible a direct comparison of the quantity of desiccated products in test rations that have replaced the raw meat and facilitates feeding operations and the recording of data.

Horses butchered on the premises provide most of the raw muscle meat, green bone, and viscera, which are ground and kept frozen in slabs until used. The rations are identical in composition except for ingredients under experimentation. Proprietáry feeds are not used because of the Government policy.

Summer and Fall Maintenance of Mature Foxes

Repeated tests at the experiment station with equalized groups of mature foxes, both male and female, have shown that 12 pounds of beef meal and liver meal, in a ratio of 4 to 1, are as satisfactory as 40 pounds of raw frozen horse meat and various kinds of viscera (3 to 1) for summer and fall feeding. The results were analyzed on the basis of relative live weight, rate of shedding of old fur, growth of new fur, and general health. The total protein in desiccated meats usually costs about one-fourth as much as that in raw meat.

The following ingredients were common to both rations: Dry mixture, 25 pounds; vegetables, 5 pounds; and ground green bone, 5 pounds. Water constituted about 23 pounds in the rations containing raw meat and 52 pounds in those with the desiccated meats. The composition of the dry mixture used in the earlier experiment was:

Dry mixture No. 6

	Pounds		*Pounds*
Bread meal	100	Fish meal (vacuum-dried)	50
Corn-flake waste	100	Kelp meal	75
Corn-germ meal	100	Skim-milk powder	50
Wheat-germ meal	50		
Alfalfa-leaf meal	50	Total	575

In the later experiments mixture No. 7 was substituted for No. 6:

Dry mixture No. 7

	Pounds		*Pounds*
Bread meal	150	Fish meal (vacuum-dried, vitamin D)	100
Oatmeal	150		
Alfalfa-leaf meal	50		
Wheat-germ meal	50	Total	500

Each animal was at first restricted to 0.8 pound of feed per day, with a gradual increase to 0.9 pound as cooler weather approached. The latter level was maintained until about January 1. On a dry-matter basis this makes approximately 6½ ounces of feed per fox per day.

Two years' work indicates that the liver meal is not essential in the summer and fall ration of mature male foxes. The substitution of hydraulic-pressure soybean meal for half the beef meal in the beef meal-liver meal ration proved entirely satisfactory during a 2-year test on the summer and fall feeding of mature vixens. Digester tankage and liver meal in proportions and quantities similar to the beef-meal rations did not prove adequate, but when one-fourth of this combination was replaced by 10 pounds of raw meat, satisfactory results were again obtained.

Rations devoid of raw meat apparently produced a good quality of fur, as revealed by careful general examination. No measurements for relative length of guard hair and underfur were taken, nor were any cross sections or tests for tensile strength made. Further study is needed to determine whether these summer and fall rations can be adjusted through addition of proteins, fats, or vitamins to produce a finer quality of fur.

The effect of such summer and fall feeding on reproduction the following spring cannot be definitely stated, but some vixens did produce large litters of strong pups, which suggests that such variability as was noted may have been due to mixed inheritance. Of the nine mature male foxes kept over for breeding, all but one sired living litters. One male that received the summer and fall ration containing beef meal and liver meal sired seven living litters.

Summer and Fall Feeding of Weaned Fox Pups

At the fur animal experiment station two equalized groups of 30 fox pups averaging 84 days old were fed rations during the summer and fall as shown in table 2. There was no appreciable difference in regard to general health, average live weight, and quantity of food consumed, but the animals in the raw-meat group showed slightly less tinge (reddish-brown color of the fur) than those in the group getting the beef meal.

TABLE 2.—*Composition of rations fed two groups of fox pups in United States Fur Animal Experiment Station test*

Ingredients	Composition	
	Group 1	Group 2
	Percent	*Percent*
Raw horse meat (muscle 3 parts, viscera 1 part)	40.0	
Steamed bonemeal	1.7	
Beef meal		10.0
Liver meal		2.0
Lard		1.0
Dry mixture No. 6	25.0	25.0
Vegetables (carrots and tomatoes)	5.0	5.0
Ground green bone	5.0	5.0
Water	23.3	52.0
Total	100.0	100.0

The substitution of beef meal and liver meal for the raw-meat portion of the ration of weaned fox pups was studied a second year with equalized groups of a similar number of animals. The average age at the beginning of this experiment was 56 days, and dry mixture No. 7 was used. The beef meal-liver meal group did not make as rapid gains through October as did the raw-meat group, yet they were only a third of a pound lighter in average weight at pelting time, in the middle of December. There was no significant difference between the groups as to feed consumption, health, or general growth of fur. The desirable animals from each group were retained as breeders and the rest were pelted. An expert in the fur trade thought the skins from the raw-meat group appeared to be brighter and more lifelike than those from the beef-meal group. Another expert thought the skins from the beef-meal group to be slightly superior; some of these skins were definitely superior to those of their litter mates fed the raw meat.

The substitution of beef meal and liver meal for the raw-meat portion of the fox-pup ration was given a third year's study with 20 animals in each equalized group and with a third similar group given a ration in which half the beef meal was replaced by an equal quantity of soybean-oil meal prepared under hydraulic pressure. Dry mixture No. 7 was used, and the pups averaged 56 days old when the experiment began. The pelts taken from animals in each group were critically studied by an expert in the fur trade. The skins from animals getting the beef meal and liver meal were judged to be the best in all respects, with the beef meal-soybean meal-liver meal group second, and the raw-meat group definitely third.

The average weight and length of body of the 9 male pup skins in each group are given in table 3. From a sample tuft of fur from the loin region of each fox 20 guard hairs and 20 underfur fibers were measured by a special instrument, and the results are also shown in the table.

Table 3.—*Average weights, measurements, and length of hairs of skins from male fox pups receiving different rations*

Test ingredients of ration	Weight of raw skin	Length of body	Length of guard hair	Length of underfur (not stretched)
	Ounces	*Inches*	*Inches*	*Inches*
Raw meat	15.5	28.58	2.40	1.48
Beef meal and liver meal	14.4	27.21	2.47	1.60
Beef meal, soybean meal, and liver meal	14.2	27.67	2.56	1.64

From these data it can be seen that though the skins from animals fed the raw meat were slightly heavier and longer, the average length of guard hair and underfur was greater in those foxes getting no raw meat in their ration.

Feeding From Breeding Time Through Lactation

The proper proportion of raw meat to include in the ration of vixens during the reproductive period was also studied at the fur animal experiment station. Two groups of vixens were fed similar rations except that one group received 60 percent of raw meat and the other group 40 percent of raw meat and an additional 6 percent of dry mixture No. 7. Vegetables and ground green bone were included in each ration. Two years' experimentation showed that the ration containing the greater amount of the more expensive raw meat gave no better results in percentage of vixens producing young or in growth of young during the lactation period. In 1 year's experimentation with equalized groups of vixens substitution of beef meal and liver meal (in a ratio of 5 to 1) for all the raw meat proved quite unsatisfactory during the lactation period. The vixens fed only the dessicated meats with dry mixture No. 6 were practically dry by the end of the fifth week of lactation. Their pups averaged nearly 1 pound less in weight at weaning than pups raised on rations containing raw meat. There was little difference in the whelping records of the two groups.

An experiment was conducted for 1 year (1938), during which a comparison was made of the three rations shown in table 4. Both rations containing only 20 percent of raw meat were satisfactory enough to warrant a more thorough investigation.

Table 4.—*Composition of three rations fed breeding vixens in tests at the United States Fur Animal Experiment Station, 1938*

Ingredients	Composition		
	Ration 1	Ration 2	Ration 3
	Percent	*Percent*	*Percent*
Raw horse meat (muscle 7 parts, viscera 3 parts)	40.0	20.0	20.0
Beef meal		4.8	2.4
Soybean meal			2.4
Liver meal		1.2	1.2
Ground green bone	3.0		
Dry mixture No. 7	25.0	25.0	25.0
Vegetables (carrots and tomatoes)	10.0	10.0	10.0
Liquid skim milk (sour)		25.0	25.0
Water	22.0	14.0	14.0
	100.0	100.0	100.0

RECOMMENDATIONS FOR FEEDING FOXES

Until more definite information is available the fox farmer should not include any great quantity of uncooked cereal in the fox ration. What is used should be finely ground. Cereals partly cooked in processing, of which oatmeal is an example, malted or dextrinized grains, or byproducts from preparation of human foods, such as dried bread crumbs and breakfast-food byproducts, are available, though higher priced than the raw cereals. These cereals provide carbohydrates and some vegetable proteins and fats. Additional protein and fat can be obtained from soybean, peanut, and linseed meals, all of which are partly cooked. It should not be forgotten, however, that foxes are carnivores and that the bulk of their ration should come from animal sources. Beef meal appears to be the most satisfactory desiccated product. Fish meal can be included. Fresh vegetables provide bulk and vitamins, as does also a small quantity of a good grade of alfalfa-leaf meal. Ground green bone gives a supply of rich animal fat, but its minerals are not needed when desiccated meats are fed. All feeds should be wholesome and sweet—that is, not rancid. Putrid meats should never be used. Flesh of livestock dying from disease may prove harmful, and dead animals should never be purchased or even accepted as a gift. Cheap meat from such animals may be fed without harmful results for a long period, but one disastrous feeding can eliminate all savings effected.

Summer and Fall Maintenance of Mature Animals

It is not necessary to feed any raw meat to mature male foxes from the end of the breeding season until January 1, or to the vixens from the time it is definitely known that they will not produce young or after they have finished their lactation period until January 1.

The following ration should give satisfactory results for maintenance of breeders during this period and for the older animals to be pelted during the fall:

	Percent
Beef meal	4.8
Soybean meal (hydraulic pressure)	4.8
Liver meal	2.4
Dry mixture No. 7 (p. 880)	25.0
Fresh vegetables (finely ground carrots and tomatoes)	5.0
Ground green bone	5.0
Water	53.0
Total	100.0

Further experimental work may show that other vegetable proteins may be substituted for part of the soybean meal and that the vegetable proteins may constitute a greater proportion of the total ration. The vitamins necessary at this time of year apparently are found naturally in sufficient quantities in the above feeds. The total amount fed should be somewhat restricted (about 0.8 pound daily per fox) for economy's sake as well as for best results until cooler weather, when the animals to be kept as breeders should receive about 0.9 pound and those to be pelted should be given a full feed. Of course, the observant fox farmer will adjust the quantity according to weight, appetite, and individual requirements of the foxes.

Vixens that have been good producers will naturally be at a minimum weight at the end of lactation and throughout the summer while the fur is shedding. The hot days are not conducive to a heavy consumption of food. During the fall under heavier feeding in addition to the slight increase in weight due to the new growth of fur, the producing animal tends to regain her body weight by putting on fat and repairing tissue. Reduced weight during summer is not in itself an indication of a good producer. Merely reducing the weight, which may be done by restricted feeding, cannot turn an inherently poor producer into a good one.

Feeding During Reproductive Period

The reserve materials essential for maximum reproduction should be built up in the bodies of the foxes (both mature animals and pups) sometime previous to mating, which occurs on the average about the first part of February. Most breeders begin richer and somewhat heavier feeding early in January, though some have reported satisfactory breeding results when they delayed it until February 1. The quality of the ration is raised by feeding a higher percentage of raw meat containing a greater proportion of high-quality glandular tissues, such as liver, hearts, brains, and spleens, in place of lungs, udders, and tripe of low biological food value. Vitamin supplements and feeds rich in the various vitamins should be incorporated in the ration.

In the light of the experimental fox feeding that has been done, and estimating from general livestock needs the requirements necessary for the fox during the period January 1 to May 30, the ration suggested in table 5 would seem to be satisfactory.

TABLE 5.—*Ingredients of suggested production ration for silver foxes, and of dry mixture included*

Ingredients of production ration	Amount	Ingredients of dry mixture	Amount	
	Percent		*Pounds*	*Percent*
Raw meat (muscle 7 parts, glandular 3 parts)	40.0	Bread meal (whole wheat preferred)	100	16
Dry mixture	25.0	Oatmeal	100	16
Vegetables, finely ground (carrots, tomatoes, lettuce leaves)	10.0	Wheat-germ meal	100	16
Green bone, ground	5.0	Fish meal, vitamin D	100	16
Water	19.7	Alfalfa-leaf meal	50	8
Cod-liver oil (fortified)	.3	Dried skim milk	50	8
		Soybean meal (hydraulic pressed)	50	8
		Linseed meal (old process)	25	4
		Wheat bran	25	4
Total	100.0	Brewers' yeast (inactive)	25	4
		Total	625	100

Canned fish may replace not to exceed 25 percent of the raw meat and raw fish not to exceed 15 percent, provided the vitamin B factor is properly taken care of.

The rations fed to vixens during the breeding season are entirely adequate for the males during this period. At the end of their season the males can be put on the summer and fall rations. Giving the males this maintenance ration when the vixens require a fuller and richer feed, because of lactation, means considerable saving in feed cost, with no harmful results during the ensuing breeding season. When it is definitely known that vixens will not produce young, they may be given the same ration as males.

The practice at the fur animal experiment station has been to feed once daily during the breeding and gestation periods a quantity that will keep the foxes in good thrifty condition, that is, as much as will be readily cleaned up within a short period. Of course, the quantity fed to individuals will vary: some foxes need more than others, and the discriminating fox man will so regulate quantities as to get the results desired and avoid waste. Appetites fall off during mating time. During pregnancy vixens should be liberally but not full fed, as full feeding tends to cause them to become fat and sluggish. The major growth of the embryos is during the extreme latter part of the gestation period. Exercise during the whole period is conducive to a more healthy condition of the animal, and this can be assured by a somewhat restricted ration. The quantity fed a few days previous to and just after whelping should likewise be restricted. Beginning about the fourth day after whelping, the vixen should be fed twice daily, the quantity being increased as the appetite improves. Full feeding should be followed as the lactation period progresses, the quantity depending on size of litter and age of pups. Stale food should not be allowed to accumulate. A graduated dial with adjustable pointer for indicating the amounts the vixens are to receive facilitates feeding operations.

Summer and Fall Feeding of Pups

During the suckling period the pups are fed with the mother, receiving the same ration. If they are weaned when they are 7 to 8 weeks old it is advisable to continue feeding them this ration until they are about 2½ to 3 months old, at which time all the raw meat can be replaced with 12 percent of beef meal and liver meal in a ratio of 4 to 1. Water should, of course, be added to make the feed of hamburger consistency. Because the pups will grow for another 3 or 4 months, the dry mixture used in the ration during the suckling period should be continued until about September 1, when the pups may be fed the same ration as that being fed the mature animals (p. 883). Late-whelped pups should receive special consideration as to quality of ration. All pups after weaning should be fed once daily, in the evening, all they will consume readily.

MINKS

CHARACTERISTICS

Mink ranching on a large scale for pelts has developed only within the last 5 years, though some pelts have been produced for more than half a century. Original stock was live-trapped from the wild. Wild mink are expert swimmers and are usually found around streams and ponds. Through selective breeding on the farms the desirable dark sepia color with a darker stripe down the middle of the back has become prevalent in the better herds. Pelts from ranch minks are now considered to be of superior quality and color to those taken in the wild.

Mature male minks weigh about 2¼ pounds and the females about half a pound less. The mating season begins about the first week in March. The males are polygamous. The length of the gestation period is not definitely known, but it is believed to be about 42 days. Litters as large as 10 are frequent, but a ranch average of 4 weaned young (kits) per female kept for breeding is considered to be satisfactory. The young minks when weaned at 8 weeks old weigh an average of three-fourths of a pound, and when they are 5 months old they weigh as much as the mature animals. The pelts are taken in the early winter of the same year. Minks breed in early spring when about 10 months old.

Minks must be kept in separate pens becasuse of their tendency to fight. Pens are of various sizes, but satisfactory ones are about 6 feet long, 2 feet wide, and 2 feet high (fig. 1, *B*). Raised wire floors are preferable (fig. 2, *B*).

Minks are not as timid as foxes nor are they as particular about their food. Apparently, they require a higher percentage of raw meat or fish in their ration than foxes. From 4 to 5 ounces of feed per day are required by mature mink not suckling young. This is placed on top of the wire over the pen or nest box or on a feeding platform.

Because mink raising is a newer enterprise than fox farming, less experimental work has been done with minks.

VITAMIN A RESERVE

The formation of urinary calculi in minks has caused considerable losses in some herds. Nothing definite is known as to the direct cause, but a vitamin A deficiency and an unbalanced mineral relationship have both been suggested as possible causes. A study of the vitamin A reserve of ranch mink and wild mink was made by Holmes and associates (*529*), but unfortunately observations were not made on the presence or absence of urinary calculi. The livers of 27 ranch-raised minks and 2 wild minks were assayed for vitamin A reserve at pelting time by the antimony trichloride colorimetric method. The wild minks averaged 975 Lovibond Blue units of vitamin A in the livers while the ranch-raised minks averaged only 62 such units. In only 2 of the ranch minks was the average of those caught in the wild approached. The ranch minks had been fed a ration composed of horse meat and fish scrap (80 percent), a commercial mink ration (20 percent), and some fresh vegetables. A more thorough study of possible dietary causes of urinary calculi formation in mink is being made by the Bureau of Biological Survey in cooperation with other agencies.

RESULTS OF DIGESTION TRIALS AT CORNELL UNIVERSITY

The first careful and detailed study of metabolism in fur animals was conducted with minks at Cornell University in 1936 (*524*) (fig. 2,

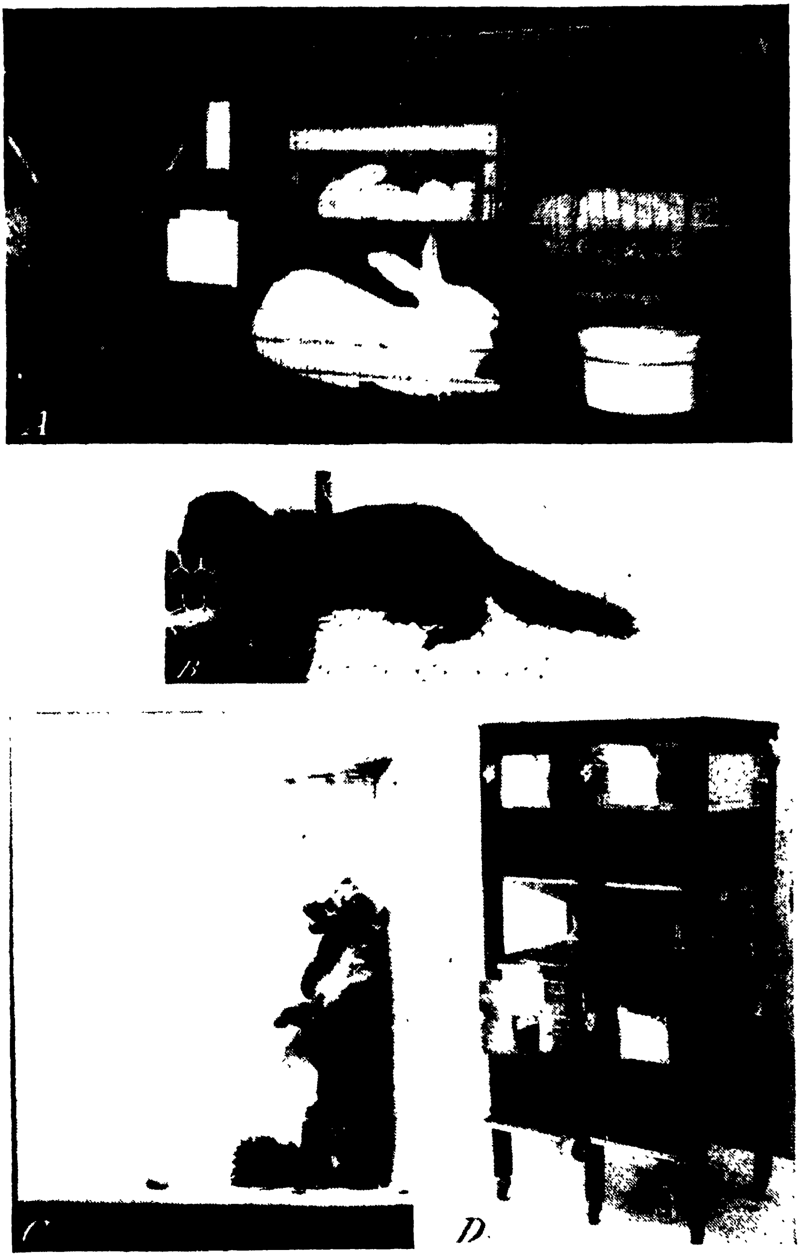

Figure 2.—*A*, Rabbits in two-compartment all-metal hutch with built-in hay manger with removable trough below for grain. Fresh water is available in the crock at all times. The young rabbits are put into the basket during hot days. *B*, Mink in wire-floored pen. (Courtesy The American Fur Breeder.) *C*, Marten in pen. (Courtesy The American Fur Breeder.) *D*, A four-compartment mink metabolism unit. Each pen has a false bottom of inch-mesh wire on which the animal stands. Feces are collected on a movable fine-mesh screen below this floor, while the urine is directed by a funnel-shaped tray to the flask under each pen. The inverted bottle on the side of each cage serves as an automatic drinking fountain. Designed and constructed at Cornell University, Ithaca, N. Y.

D). The diets used in this metabolism study are listed in table 6. It was necessary to mix some water with all except diet 5. Dry mixtures A and B are given in table 7; a chemical analysis and the digestibility coefficients of the six diets are given in tables 8 and 9.

TABLE 6.—*Diets used in metabolism studies on minks*

Ingredients	Portion of ingredient in diet No. — 1	2	3	4	5	6
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Fresh lean beef	10	10	10	10	10	5
Canned fish	2	2	2	2	2	1
Fresh lamb liver	3	3	3	3	3	3
Fresh lettuce	1	1	1	1	1	1
Dry mixture A (cereal cooked)	5					
Dry mixture A (cereal uncooked)		5				
Commercial dry mixture No. 1			5			
Commercial dry mixture No. 2				5		
Dry mixture B (cereal cooked)						[illegible]

TABLE 7.—*Dry mixtures A and B by weight*

Ingredients	A	B	Ingredients	A	B
	Lb.	*Lb.*		*Lb.*	*Lb.*
Oatmeal	30.0	10.8	Calcium carbonate	1.5	1.5
Yellow cornmeal	22.0	8.0	Iodized salt	.5	.5
Wheat middlings	25.0	9.2	Fortified cod-liver oil	.3	.3
Dry skim milk	10.0	10.0	Dried meat scraps		40.0
Yeast	5.0	5.0			
Dried blood	5.0	5.0	Total	90.3	91.3
Bonemeal	1.0	1.0			

TABLE 8.—*Analysis of diets 1 to 6 on a dry-matter basis*

Diet No.	Ash	Crude protein	Ether extract	Nitrogen-free extract	Crude fiber
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
1	4.6	40.9	15.2	38.0	1.3
2	5.3	37.9	19.8	35.0	1.9
3	11.6	44.7	17.3	23.0	3.3
4	5.7	37.2	29.5	24.6	3.0
5	4.7	54.3	37.7	2.8	.6
6	12.1	55.0	11.6	19.2	2.0

TABLE 9.—*Digestibility coefficients of diets Nos. 1 to 6*

Diet No.	Trials	Dry matter	Matter not ash	Crude protein	Ether extract	Nitrogen-free extract	Crude fiber
	Number	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	3	81	83	89	93	73	37
2	4	71	73	85	94	52	2
3	4	70	76	84	96	51	31
4	4	77	80	81	97	62	24
5	2	89	91	91	96		
6	4	68	72	82	91	36	40

[1] Analysis for 1 trial only

The digestion trials on each diet were run by confining the animals in a special cage so designed by the investigators that complete and separate samples of urine and feces could be obtained over a 24-hour period. The most digestible diet was that containing no dry mixture (No. 5). The diet containing the dry mixture formulated by the Cornell Animal Nutrition Laboratory, in which the cereal was cooked (No. 1) proved second most digestible. The least digestible of all the rations and the one showing the lowest digestibility of crude protein was that containing desiccated meat products (No. 6). The average digestibility of the protein was 85 percent, with significant differences between a few of the values. The digestibility of the fat (ether extract) was also uniform and high for all the diets. The investigators report as follows (*524*):

> The digestibility of the carbohydrate fraction, represented by the nitrogen-free extract, is highly variable for the different diets. This variability is the most important factor affecting the digestibility of the dry matter as a whole. Since the digestibility of the nitrogen-free extract is also much lower than that of the protein or the fat, it appears that mink are not able to digest carbohydrates as well as these other nutrients. By comparison of the data for diets 1 and 2 . . . it is indicated that the starch in the grains is made more available to the mink by cooking.
>
> No special significance can be placed on the data for digestibility of the crude fiber, since it is such a small part of each diet. The data indicate, however, that the mink is able to digest only a small fraction of the higher carbohydrates. This can be explained by the fact that the food remains in the body for such a short time that the bacterial action necessary to digest cellulose takes place to only a very limited extent.

STUDIES AT THE UNITED STATES FUR ANIMAL EXPERIMENT STATION

The small number of minks thus far available at the United States Fur Animal Experiment Station has permitted only preliminary feeding experiments. W. P. A. construction in 1938 provided equipment and pens for more than 450 animals.

In the feeding trials that have been run at the station an effort has been made to determine what can be substituted for the more expensive raw meat of the minks' ration. The substitution of ground fresh codfish for half the raw frozen horse meat in the summer and fall ration of mature minks resulted in as good general health, food consumption, and fur growth as the ration containing the full portion of raw meat, though the animals getting the codfish weighed less at the end of the test. A similar ration fed to weaned kits gave a slight indication of unpalatability. A third group of mink kits getting all codfish in place of meat were unthrifty and only 50 percent of them finished the experiment. Many mink breeders have fed a much higher proportion of other kinds of fish in the total diet with satisfactory results. One year's experiment in replacing one-third of the raw-meat portion of the mature minks' summer and fall ration with an equal weight of canned ocean fish in one ration and an equivalent weight of fish meal (on basis of dry matter) in another gave results of no significant difference.

Results of feeding of similar rations to kits suggest that either canned fish or fish meal in the proportions used is adequate as measured by general health, food consumption, average live weight, and fur growth.

Desiccated meats are apparently not so satisfactory as a partial substitute for the raw-meat part of the ration for minks as for foxes. The substitution of tankage and liver meal (ratio 4 to 1), on a dry-matter basis, for half of the 40 percent of raw meat in one ration, and a like substitution of beef meal in another ration, were less satisfactory for the growing out of weaned kits to pelting time than the ration containing 40 percent of raw meat. Likewise a ration in which tankage and liver meal (ratio 4 to 1) were substituted for one-half of the 40 percent of raw meat proved less satisfactory than the ration containing a full portion of raw meat for the summer and fall feeding of mature minks, as evidenced by late shedding of the old fur and poor growth and quality of the new, as well as by poor gains in live weight.

A mixture of equal parts of bread meal, oatmeal, and raw corn meal constituting 25 percent of the ration gave better weights and growth with a small number of weaned kits than an equal quantity by weight of a dry mixture composed of eight ingredients (mixture No. 6, p. 880) in another ration.

RECOMMENDATIONS FOR FEEDING MINKS

The experience of successful mink raisers and the few experimental results available indicate that minks should be fed a ration containing more raw meat than is necessary for foxes. The amount of raw meat should be about 50 percent of the ration during the summer and fall and as much as 70 percent during the breeding season and lactation periods. This raw meat can be muscle meat (2 parts) and viscera (1 part) of either horse, cow, or sheep. The viscera may be heart, liver, kidneys, spleen, or brains in varying proportions. A variety is desirable. Some tripe, udders, and lungs can replace the other organs during the summer and fall. Whole fresh-ground fish or canned fish may be substituted for as much as 33 percent of the raw meat. Contaminated fish or meat should never be used. Chicken or rabbit heads or rabbit carcasses can be used if fresh. The dry mixture suggested for foxes during the breeding season should prove satisfactory when constituting 10 to 15 percent of the mink ration during the breeding season. Dry mixture No. 7 (p. 880) can be used during summer to the extent of 25 percent of the ration. The ground green bone should be 5 percent; and tomatoes, carrots, turnips, green lettuce, and other ground vegetables, 5 percent. Salt should be added to the extent of about 0.5 percent of the ration as fed. The remainder should be water or clean, fresh milk, sufficient to make the entire ration of hamburger consistency. As a precautionary measure 0.3 percent of fortified cod-liver oil should be added to the ration.

Minks should be full fed twice daily while suckling their litters. At other times one feeding in the evening is all that is necessary for adults, and this should be so restricted in quantity that the animals will not get too fat.

MARTENS AND FISHERS

Martens (fig. 2, *C*) and fishers are fur animals of the forest. They are related to the highly prized Russian sable. The raising of these animals in captivity has never been profitable because they do not reproduce satisfactorily under such conditions. Some of the early difficulty was due to the fact that it was not known that martens breed in July and August and have a gestation period of 9½ months (*39*) and that fishers have a gestation period of over 11 months and breed within a few days after giving birth to the young in the spring. The young are large enough to be pelted the fall of the same year in which they are whelped.

At the United States Fur Animal Experiment Station only 10 to 15 percent of the female martens produce young. Evidently the methods of management or the ingredients of the ration are not adequate for efficient reproduction. Yet both martens and fishers can be maintained and satisfactorily furred out on the rations containing raw meat that have been fed to foxes. Rations containing as much as 75 percent of raw meat and viscera have not been effective in increasing reproduction in martens. Rations well fortified with ingredients rich in the various vitamins have likewise proved ineffective. During the past year a colony of rats was maintained for supplying these animals in the rations at periodical intervals. Sexual activity has always been evident in the martens fed all rations at the station, but litters are not forthcoming in the spring. Until more definite information on feeding for successful reproduction is available it will be impossible to give any recommendations for feeding either martens or fishers.

DOMESTIC RABBITS

Domestic rabbits are raised for meat and fur in every State, and the total production in the United States may exceed 7,000,000 animals a year. Even though all the skins are readily salable to the hatters' trade and a small percentage to the fur trade, rabbits are produced in this country primarily for meat because of its higher relative value.

A medium-type rabbit— females (does) weighing 10 to 12 pounds at maturity and males (bucks) 9 to 10 pounds— is most widely used in commercial rabbitries. The animals are confined to individual hutches about 2 feet high with a floor 2½ by 4 feet (fig. 2, *A*). The gestation period in rabbits is from 31 to 32 days.

The commercial practice is to push the young animals by heavy feeding so that they will attain a desirable marketable weight when 8 weeks old, and then to breed the doe again just as soon as she weans a litter. As many as four litters a year of seven or eight young per litter are produced by each doe in the milder climates.

Earlier experimental work seemed to indicate that grains should be rolled and that a good-quality hay should constitute approximately 60 percent of the rabbits' ration. Later work with a self-feeder having compartments, perfected at the United States Rabbit Experiment Station, Fontana, Calif., showed that rabbits preferred the whole grains, such as oats, wheat, barley, and sorghum, and actually made better gains on them than on the same grains rolled, ground, or pelleted. It was also found that a protein supplement such as soybean meal, peanut meal, or linseed meal was very essential to maximum gains, and that these should be supplied either in pelleted or pea-sized cake form. The pellets should be three-sixteenths of an inch in diameter and one-eighth of an inch long. Under such a system of feeding the rabbits consumed about 2½ pounds of concentrates for every pound of hay, and these quantities of feed (including that fed the doe during pregnancy) produced 1 pound of live weight on rabbits weaned at 8 weeks of age.

The Bureau's recommendations are now that in commercial rabbitries the does while suckling young be self-fed with at least two of the whole grains and one of the protein supplements (pelleted or pea-sized cake) in a self-feeder or that they be full-fed by hand with two parts of a mixture of any two or more of the smaller grains (relative price the primary factor) and one part protein supplement in pelleted or pea-sized cake form. Clean, bright, leafy legume hay (alfalfa, clover, lespedeza, or pea-vine) cut into 3- to 4-inch lengths should be available in the hay manger at all times. A small quantity of succulent green feed or roots should be supplied daily. White block salt and fresh water should be kept before the rabbits at all times. No vitamin supplements are necessary. Cod-liver oil should not be given, since it is toxic to rabbits.

After the doe weans her litter she should be fed once daily, at evening, a quantity of concentrates that will be readily consumed in 20 to 30 minutes. This restricted ration prevents her becoming too fat. The concentrate mixture should be four parts of any two or more of the small grains and one part of the protein supplement (pelleted or cake form). A small amount of green feed should be supplied and legume hay, salt, and fresh water in abundance. Herd bucks and developing does and bucks can be fed the same ration. Naturally, a careful feeder will adjust rule-of-thumb methods to the specific requirements of individual animals so as to get the best results. More detailed information on the subject is available in publications obtainable by request from the United States Rabbit Experiment Station, Fontana, Calif., or the Bureau of Biological Survey, Washington, D. C.

FEEDING REQUIREMENTS OF GALLINACEOUS UPLAND GAME BIRDS

by Ralph B. Nestler[1]

WITH an awakened public interest in the preservation of wild life, more and more farmers, 4-H Club members, and others are raising upland game birds. Also, more attention is being given to the right kind of feeding practices. This article discusses the feeding of these birds in the wild and in captivity.

THE IMPORTANCE of a knowledge of game nutrition and satisfactory feeding practices is gradually being impressed upon game managers and others interested in game throughout the country. For more than half a century civilization has been forcing game almost to extinction. One notable example is the complete destruction of the heath hen, or eastern pinnated grouse. At one time this bird was found in large numbers in Massachusetts, southern New Hampshire, New York, Pennsylvania, and New Jersey. Its last stand was on the island of Martha's Vineyard, Mass., where it existed for many years after its extinction in other sections of the country. In 1930, only one bird of this species could be found there.

In recent years, certain foresighted citizens have realized the need of help for wildlife. Through their efforts game refuges have been started, feeding grounds are prepared especially for the game, and artificial game propagation has become a business. The work of game preservation and replenishment by both State game commissions and private individuals has made such strides in recent years that it has passed the trial-and-error stage and reached the field of scientific research.

This article attempts to show what has been done in the field of nutrition and feeding of gallinaceous upland game birds and what still remains to be done. Because much of the work on game to date has pertained to these species and because of space limitations, other kinds of game, including game mammals, marsh and aquatic game birds, pigeons, and doves, are not here considered.

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[1] Ralph B. Nestler is Associate Biologist, Bureau of Biological Survey. Appreciation is expressed to H. W. Titus, in charge of Poultry Nutrition Investigations, Bureau of Animal Industry, and Arnold Nelson, Section of Food Habits, Bureau of Biological Survey, for their helpful suggestions, assistance, and constructive criticism of this article. (The Bureau of Biological Survey was transferred from the Department of Agriculture to the Department of the Interior July 1, 1939.)

THE UPLAND GAME BIRDS

Gallinaceous upland game birds belong to the superfamily Phasianoidea, of the order Galliformes. This superfamily is divided into four groups—(1) grouse, ptarmigans, and the sage hen (the Tetraonidae family); (2) American quails and Old World partridges (the Perdicidae family); (3) pheasants (the Phasianidae family); and (4) turkeys (the Meleagrididae family). The 13 most important species in continental United States on which some work has been done in captivity are ruffed grouse, sharp-tailed grouse, prairie chicken or pinnated grouse, sage hen, bobwhite quail, mountain or plumed quail, California or helmet quail, Gambel's quail, scaled quail, Hungarian partridge, chukar partridge, ring-necked pheasant, and wild turkey.[2] Until very recently, only the bobwhite quail, the ring-necked pheasant, the Hungarian partridge, and the wild turkey have been propagated successfully in captivity to any great extent. Other species of quail also are now being raised in this way with success.

GROUSE

Of the Tetraonidae family, the ruffed grouse, commonly called partridge in New England and pheasant in the southern Allegheny States, is probably the best known generally, and is one of our most esteemed native game birds. This species ranges from the Atlantic to the Pacific and from Canada to the higher ground of the Southern States. In 1884 85, Pierre Lorillard turned ruffed grouse loose on the game reserve at Jobstown, N. J., with satisfactory results. Successful implantations were made in 1900 on a 1,500-acre tract on Washington Island, Wis., by William Barnhard. Birds shipped from Alberta, Canada, to an island in Puget Sound, Wash., in 1923, have also done very well.

Game propagators have found that the proper care of ruffed grouse in pens is very difficult. Adult native birds usually are too wild for controlled conditions. On the other hand, propagated stock brought to maturity is usually too tame for planting in the wild.

The sharp-tailed grouse is not so familiar to most people as the ruffed grouse, and it has not received as much attention from the game propagators. It is found in eastern Colorado, central Nebraska, eastern South Dakota, Minnesota, Utah, northern New Mexico, and western Wisconsin.

Changes in the center of the prairie chicken population as related to human settlement of this country are still in process. This bird formerly ranged throughout all the open country between the Appalachian and the Rocky Mountains and from Canada to the Gulf coast. As the country became more thickly populated, the prairie chicken has disappeared from many regions, and the eastern limit of its range has moved westward. At the same time, the clearing of forests has provided much new open country that it has been prompt to occupy. In this way, its range has extended westward and northward, and at the same time has been curtailed eastward. It is a gregarious bird and is easily domesticated, but it has not been propagated successfully in captivity.

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[2] The scientific names of these species are *Bonasa umbellus* (ruffed grouse), *Pedioecetes phasianellus* (sharp tail[illegible]), *Tympanuchus cupido* (prairie chicken or pinnated grouse), *Centrocercus urophasianus* (sage he[illegible] *virginianus* (bobwhite quail), *Oreortyx picta* (mountain or plumed quail), *Lophortyx californicus* (C[illegible] or helmet quail), *Lophortyx gambeli* (Gambel's quail), *Callipepla squamata* (scaled quail), *Perdix per*[illegible] (Hungarian partridge), *Alectoris graeca chukar* (chukar partridge), *Phasianus colchicus tortuatus* (ring-necked pheasant), and *Meleagris gallopavo* (wild turkey).

The sage hen is found in the sagebrush plains of the Transition Zone from northwestern North Dakota to central California, northwestern New Mexico, and northwestern Nebraska. It has not been raised successfully in captivity.

QUAILS AND PARTRIDGES

The very popular bobwhite is more widely distributed in the United States than any other species of the Perdicidae family. In the North it is commonly called quail, whereas in the Southern States it is generally designated partridge. It is very abundant and is the principal upland game bird of the Gulf and South Atlantic States. It ranges westward to the elevated central Plains from South Dakota to Texas. The distribution of the bobwhite in the Northeast is more restricted now than it was about 50 years ago, and the present stock seems unable to occupy the colder regions of the New England States, where at one time the bird lived successfully. This withdrawal of bobwhite from the cold interior of the Northeast to the warmer coastal belt probably goes hand in hand with the decline of agriculture in New England and a nearly complete failure of the winter food supply. Introduction of the bobwhite into Washington, Colorado, and Montana west of the Divide has met with moderate success, but implantations in California, Arizona, New Mexico, Utah, Wyoming, South Dakota, and Minnesota have failed.

Bobwhite are amenable to large-scale rearing in captivity. William Coleman of Virginia pioneered in the development of techniques and electrical equipment for successful quail propagation, and in 1929 succeeded in raising very large numbers of birds successfully with electric incubators and brooders. Only a few years prior to this, all hatching and rearing had been done with bantam hens.

The various other American quail, such as the mountain quail, the California quail, and Gambel's quail, also may be raised in captivity. Their eggs may be incubated successfully under bantam hens, and for some species electrical incubation has been tried. The mountain or plumed quail is confined to the mountainous sections of the Pacific Coast States; the California or helmet quail likewise is localized more or less on the west coast; and Gambel's quail inhabits Texas, Arizona, and New Mexico, from which it is rapidly spreading to surrounding States, especially California and Nevada.

The scaled quail, known also as the white topknot and the blue quail, is one of the most interesting game birds of the Southwestern States. It is found in abundance locally and ranges through New Mexico and Arizona to Colorado, Oklahoma, west Texas, and Kansas.

The European or Hungarian partridge was introduced into this country by Richard Bache in the latter part of the eighteenth century, when he stocked his plantation near Beverly, N. J. Subsequent plantings were made in Virginia and other parts of New Jersey. In 1904, this exotic bird was planted in North Carolina and did moderately well for a time on breeding grounds planted to cowpeas. The next year a wave of importation began along the entire Atlantic coast. Importations were made in Connecticut, Pennsylvania, and New Jersey, on a very large scale. For a while the results were encouraging, but by 1920 practically all the birds had disappeared. Recent attempts to implant this species in the North Central States have met with varying success. It seems, however, that the Hungarian partridge has a good chance of becoming established in the grain-producing section of the Midwest.

The chukar partridge has a number of other names, derived mainly from its loud double call—"kau-kau," "keklik," "Indian chukor," "chickore," "chukar red-legged partridge," "chuckare," and "chukru." The chukar is a native of India, but it is found also in large numbers in north China, from which place it has been imported to this country. It was introduced first in California, and is now being reared and experimentally stocked by a large number of State game departments, including those of Washington, Idaho, Montana, Wisconsin, and Kansas.

This species may be found at all altitudes, from sea level to 16,000 feet, but its preference seems to be for elevations between 3,000 and 4,000 feet. Typical chukar country is rocky and arid, with little brush.

The chukar is an excellent game bird, comparing well with the Hungarian partridge. It adapts itself well to confinement. Artificial incubation of chukar eggs and artificial brooding of the chicks may be done successfully.

PHEASANTS

One of the most popular game birds in the United States today is not indigenous to this country. The ordinary game pheasant, called variously English pheasant, Chinese pheasant, Mongolian pheasant, ringneck, and English ringneck, is a cross between the common pheasant (*Phasianus colchicus*) and the Chinese pheasant (*P. torquatus*).

Records indicate that the pheasant was first introduced to our soil in New Jersey in 1790 by Richard Bache, son-in-law of Benjamin Franklin, but the implantation failed. The first successful introduction was made in Oregon by O. N. Denny, consul-general to Shanghai, China, in 1881. On the east coast an effective implantation was made in 1887 by Rutherford Stuyvesant on his Tranquillity Game Preserve in New Jersey. Nowhere in the United States has the pheasant shown more remarkable increases than in the Middle West. The principal pheasant State is now South Dakota, where the first public stocking was made in 1912. In the Northwest also the species is holding its place, but in the Southern States the birds do not thrive when placed on their own resources. Numerous liberations have been made in the Southeastern and Southwestern States, but they have not resulted in establishing the species in either of these regions.

Pheasants breed freely in captivity; they and the bobwhite are the two most commonly propagated species of game.

WILD TURKEYS

A pure strain of wild turkey is very rare, and can be found in only a few places, such as the Santee River Basin in South Carolina. Probably the foremost reason for the disappearance of the pure stock is the readiness with which wild turkeys fraternize with domestic stock. Promiscuous mating between the two strains has produced large numbers of partly domesticated game birds. These hybrids are quite plentiful in various forested sections of the Central and Southern States.

Propagated wild turkeys are frequently too tame for release in the wild. To preserve their wildness, the birds must be confined closely in a location away from all domestic stock. The game commissions of Pennsylvania, Michigan, Maryland, and Virginia have been quite successful in propagating wild turkeys. Some of the Pacific, Southwestern, and Midwestern States also are becoming active in this work.

EXTENT OF UPLAND GAME PROPAGATION

Some idea of the extent to which upland game birds are propagated artificially may be obtained from a recent survey made by Clarence Cottam of the Bureau of Biological Survey, at the close of 1938, of the game breeders throughout this country (data unpublished). Of 6,302 questionnaires mailed out to possible dealers in the United States whose names were mentioned in game magazines or suggested by State game commissioners, 2,121, or 33.7 percent, were returned. Forty-seven States and the District of Columbia are represented. The report is given in table 1.

TABLE 1.—*Number of dealers in gallinaceous upland game bird species at close of 1938*

Grouse	Dealers	American quail	Dealers	Old World partridge	Dealers
	Number		*Number*		*Number*
Ruffed	24	Bobwhite	324	Hungarian	64
Sharp-tailed	8	California	118	Bamboo	24
Dusky	4	Valley	116	Francolin	6
Spruce	3	Gambel's	71	Red-crested Wood	4
Sage	3	Mountain	60	Himalayan Hill	3
Ptarmigan, rock	1	Scaled	59		
		Texas bobwhite	32		
		Mexican bobwhite	22		
		Masked bobwhite	17		
		Mearn's bobwhite	12		

Pheasant	Dealers	Wild turkey	Dealers
	Number		*Number*
Ring-necked	544	Eastern	60
Chinese	315	Rio Grande	9
		Florida	5

M. C. Wilson, in charge of extension studies and teaching, Extension Service, United States Department of Agriculture, has reports from 182 counties in various sections of the country, of 33,026 game birds produced by 4-H Club members during 1937; and from 167 counties, of 213,374 game birds produced by adults.

These figures do not include game birds propagated by the various State game commissions or the Bureau of Biological Survey, whose contributions to our game resources are very large.

PHYSIOLOGY OF UPLAND GAME BIRDS

Like the barnyard chickens and turkeys the majority of upland game birds are gallinaceous fowls. They are mostly rather large.

heavy-bodied birds, with comparatively short wings, poorly adapted for long flights. The legs are adapted for running and for scratching the ground, where most of the food, which consists of seeds, worms, etc., is found.

Food takes the following course through the digestive system of a gallinaceous bird (*603*):[3]

Swallowed with the assistance of the tongue, the food is forced through the system by means of the muscles that line the digestive tract (fig. 1). If the bird has been without food for several hours, the first few mouthfuls go direct to the gizzard, the grinding organ of the body, within a few seconds. If, however, the fowl has been feeding more or less continuously, additional food will be stored in the crop until the gizzard is emptied of a part of its contents. As the food passes from the storage pouch to the gizzard, it pauses for a short time in the proventriculus, or stomach.

The rhythmic contractions and relaxations of the gizzard exert sufficient pressure to grind the food to a fine mass, which passes to the small intestine. There it is thoroughly mixed and brought into contact with the walls of the intestine. It then passes to the large intestine. Two blind pouches, called ceca, are located at the junction of the small and large intestines and open up into the tract. These pouches rhythmically expand and contract and thus receive and reject the intestinal contents. The remaining material, which is now in a semiliquid condition, passes through the large intestine to the cloaca, where portions of it are expelled at intervals.

Titus points out (in an unpublished communication) that—

> digestion is extremely rapid in the domestic fowl. In as little as 1½ to 2 hours after the feed leaves the crop, an individual portion may be digested and the indigestible residue voided. However, for the complete digestion of a full meal, as little as 10 hours or as much as 18 hours may be required; the average time is close to 14 hours but may be appreciably less when nothing but a wet mash is fed.

NUTRITIONAL DIFFERENCES AMONG SPECIES

Even though the digestive systems of the various species of gallinaceous birds are similar and in many respects the nutritive requirements are identical, nevertheless certain differences are quite pronounced between the various families of the Galliformes order. The nutrition of the common chicken as compared with that of the domesticated turkey furnishes a good example. A laying diet formulated to meet the maintenance and reproductive requirements of the former will likewise satisfy the requirements of the latter, but this agreement does not hold true in regard to rearing diets for the growing birds. Turkey poults, because of their more rapid rate of growth, require about 4 percent-units [4] more crude protein, two and a half times more vitamin A, twice as much vitamin D, and somewhat more calcium and phosphorus than do chicks. Also, workers in California (*679*) have found that an acute dermatitis will develop in turkey poults as a result of vitamin G (riboflavin) deficiency, in spite of the fact that the diet contains an ample supply of the "filtrate factor," which prevents dermatitis in chicks. In turkeys this skin disorder is completely prevented by riboflavin. On the other hand, the symptoms of

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[3] Italic numbers in parentheses refer to Literature Cited, p. 1075.

[4] A percent-unit is the difference between two percentages.

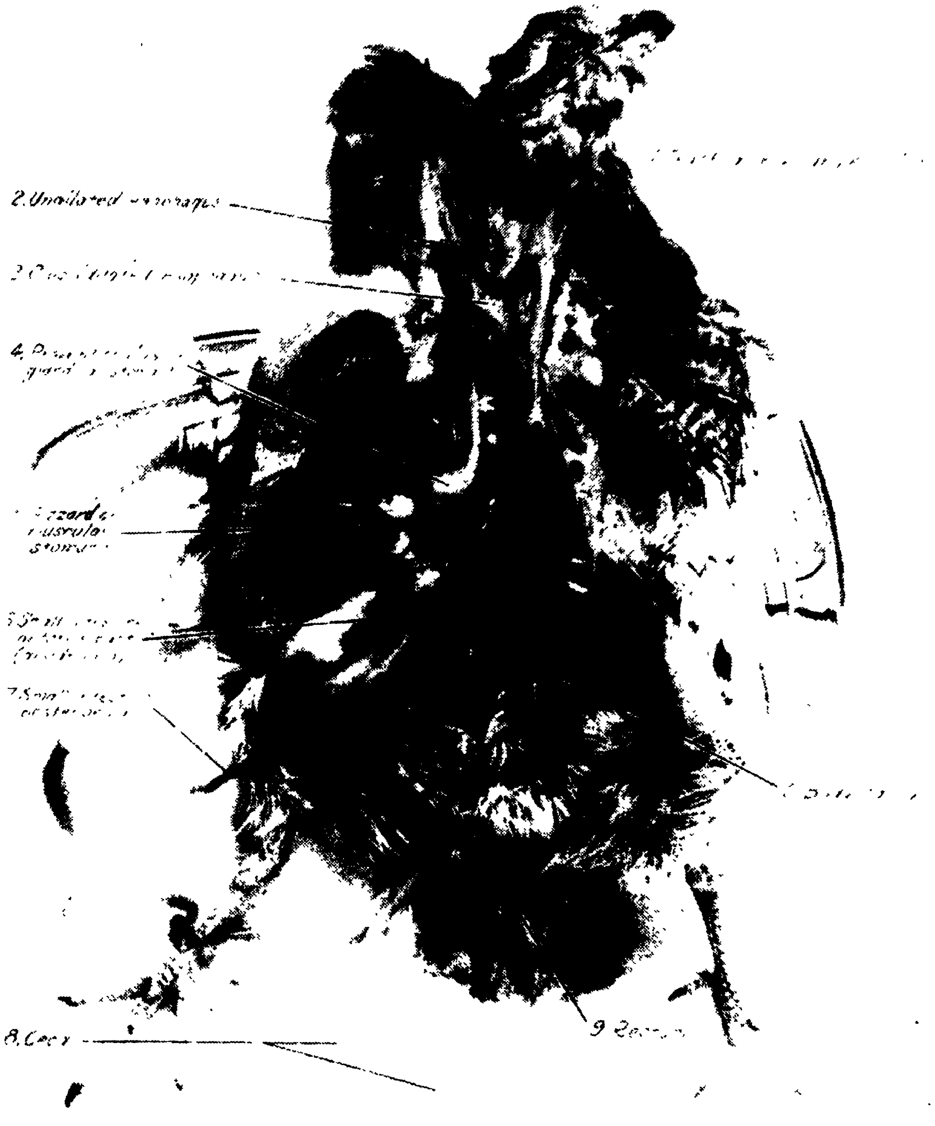

Figure 1.—Quail opened and viscera spread out. Digestive enzymes function in the following tracts: 2. Undilated esophagus—ptyalin in salivary secretions converts starch into maltose; 4. proventriculus—pepsin in gastric juice converts proteins into proteoses and peptones; 6. duodenum—amylopsin in pancreatic juice converts starch into maltose; lipase in pancreatic juice converts fats into glycerol and fatty acids; and trypsin in pancreatic juice converts protein into proteoses, the latter into peptones and polypeptids and some amino acids; 7. small intestine (posterior part)—maltase in intestinal juice converts maltose into glucose; sucrase in intestinal juice converts sucrose into glucose and fructose; erepsin in intestinal juice converts peptone into amino acids. (Photograph from Stoddard's The Bobwhite Quail; Its Habits, Preservation and Increase, 1931, by permission of Charles Scribner's Sons, publishers.)

vitamin G deficiency in chicks are slow growth, diarrhea, and emaciation, without dermatitis.

Among the game birds, differences in the types of natural food selected by the various species indicate that nutritional variation also exists among related birds in the wild. The ruffed grouse, for instance, feeds almost entirely on browse (leaves, buds, and tender shoots) and berries, whereas the California quail and wild turkey subsist mainly on seeds, grains, mast, and insects.

NUTRITIONAL STUDIES ON GAME BIRDS UNDER NATURAL CONDITIONS

TYPES OF FOOD UTILIZED

Fairly complete investigations of the food habits of game birds in the wild have been made by the Bureau of Biological Survey (fig. 2). Some of the State game commissions also have obtained data along this line for certain local species. Inasmuch as a knowledge of the natural selection of foodstuffs is a key to the solution of the nutritional riddle, some of the more pertinent facts are presented.

Seven types of food material are utilized by the upland game birds:

(1) *Weed seeds.*—With the exception of the ruffed grouse and the prairie chicken, game birds eat very large quantities of miscellaneous seeds, many of them being from obnoxious weeds. Seeds of beggarweed, bushclover, Japan clover, butterfly pea, ragweed, pigweed, sheep sorrel, partridge-pea, foxtail, smartweed, black bindweed, and lambsquarters are some of those found.

(2) *Animal food.*—Grasshoppers, crickets, locusts, weevils, beetles, ants, flies, bees, earthworms, and snails.

(3) *Seeds of cultivated plants.*—Grains: Wheat, barley, oats, buckwheat, benne, corn, kafir, millet, sorghum, rice, and rye. Legumes: Soybeans and cowpeas.

(4) *Mast.*—Seeds of the pine, oak, sweetgum, maple, and ash.

(5) *Browse* (used especially by the grouse).—Leaves of chickweed, field sorrel, Christmas fern, spruce, clover, woodsorrel, hawkweed, and mountain-laurel; twigs and buds of maple, mountain-ash, hazelnut, apple, cherry, aspen, birch, American hornbeam, and American hophornbeam.

(6) *Fruit.*—Blackberry, partridgeberry, smilax, grape, sumac, black cherry, dewberry, and red mulberry.

(7) *Mineral.*—Limestone pebbles, bits of oyster shell, particles of sandstone, and quartz pebbles.

FOOD SELECTION AND HABITS

Table 2 shows in general the food habits of adult upland game birds, though the figures given are far from conclusive. As averages, they merely indicate what certain species might eat at any one time. The food selection by individuals of a species may vary considerably from that of the species as a whole. For instance, when Kelso (*615*) analyzed the crop contents of Hungarian partridges, he found that 40 percent of the diet of one bird consisted of grasshoppers, whereas 85 percent of the diet of another was composed of coulee crickets.

The nature of the flora on the local feeding ground also influences the diet. In areas where there are large raspberry thickets pheasants

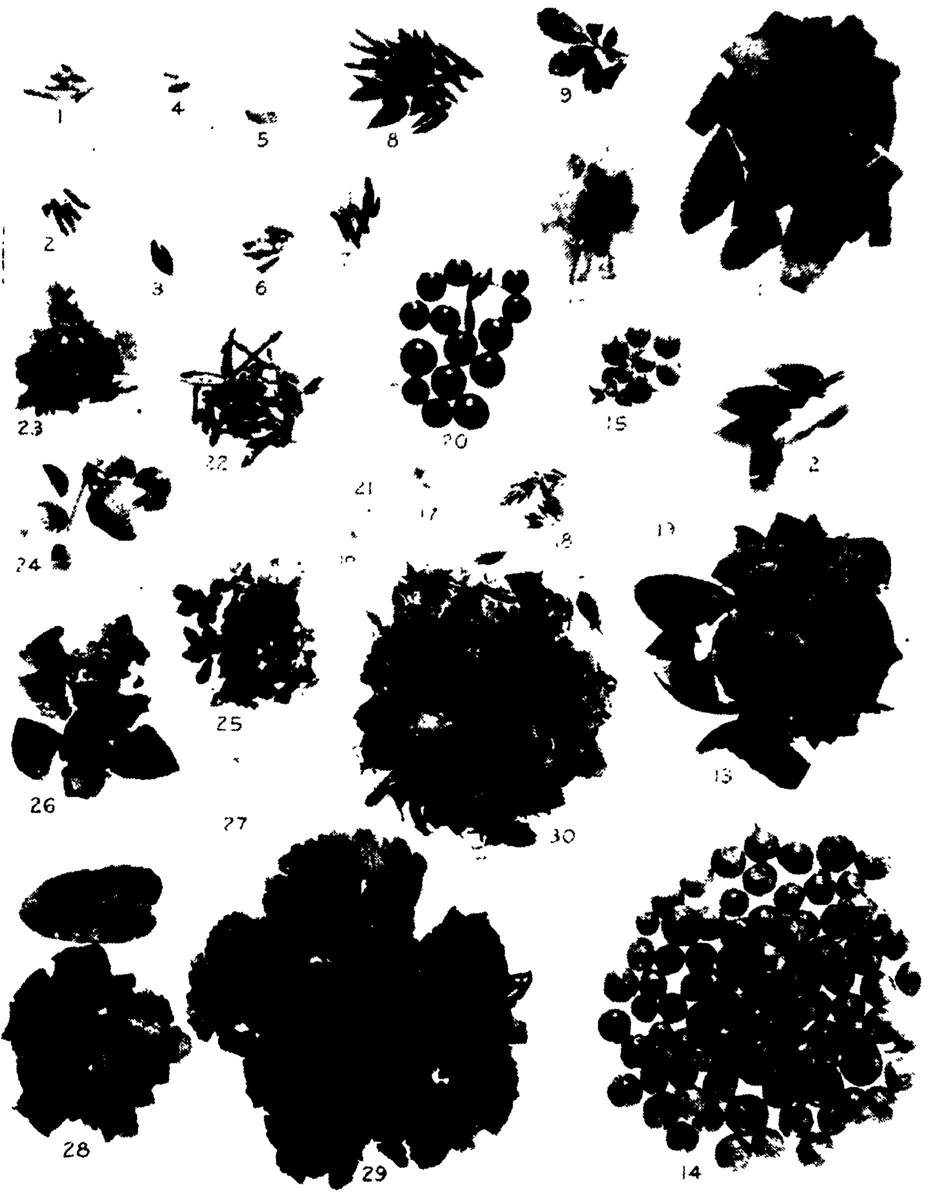

Figure 2.—Crop contents of one ruffed grouse collected on the George Washington National Forest, December 1935. The 30 food groups were identified as follows: 1, Menziesia (*Menziesia pilosa*); 2, buds of pin cherry (*Prunus pennsylvanica*); 3, seed of witch-hazel (*Hamamelis virginiana*); 4, buds of trailing-arbutus (*Epigaea repens*); 5, buds of hickory (*Carya* sp.); 6, buds of black gum, or tupelo (*Nyssa sylvatica*); 7, Canada hemlock (*Tsuga canadensis*); 8, serviceberry (*Amelanchier canadensis*); 9, leaves of rose family (Rosaceae); 10, buttercup (*Ranunculus* sp.); 11, Christmas fern (*Polystichum acrostichoides*); 12, panic grass (*Panicum* sp.); 13, leaves of wintergreen (*Gaultheria procumbens*); 14, fruit of wintergreen; 15, seed capsules of mountain-laurel (*Kalmia latifolia*); 16, moss (Musci); 17, bushclover (*Lespedeza* sp.); 18, buds of mountain-laurel; 19, undetermined leaf; 20, greenbrier (*Smilax* sp.); 21, oxalis (*Oxalis* sp.); 22, blueberry (*Vaccinium* sp.); 23, cinquefoil (*Potentilla* sp.); 24, partridge-berry (*Mitchella repens*); 25, stonecrop (*Sedum nevii*); 26, leaves of trailing-arbutus; 27, undetermined leaf; 28, selfheal (*Prunella vulgaris*); 29, aster (*Aster* sp.); 30, sheep sorrel (*Rumex acetosella*).

TABLE 2.—*Food habits of upland game birds—average monthly basis*

Species	Birds studied	Animal food	Vegetable food: Total	Vegetable food: Miscellaneous	Vegetable food: Seeds, weeds, and grass	Vegetable food: Mast	Vegetable food: Grain	Vegetable food: Browse	Vegetable food: Fruit	Grit [1]	Authority
	Number	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	
Ring-necked pheasant	100	11.0	89.0		6.0		78.0				M. H. Swenk (*1114*).
	[2] 14	.1	99.9	23.8	23.7		15.7	36.7			A. M. Leffingwell (*673*).
Bobwhite	45	14.5	85.5	13.4	9.5		36.7	5.5	5.5	26.2	C. Cottam (*228*).
		16.7	83.3		50.0	2.5	16.7		10.0		F. E. L. Beal (*71*).
	1,659	14.5	85.5		47.9	13.4	3.0	4.3	19.4	[3] 3.5	H. L. Stoddard (*1105*).
Scaled quail	258	21.9	78.1		59.2		9.4	9.5		11.0	Leon Kelso.[4]
California quail	619	3.0			65.5		5.0	25.0	2.3		W. L. McAtee (*706*).
Hungarian partridge	80	6.0	94.0	5.3	20.4		17.9	20.4		10.0	Leon Kelso (*615*).
Ruffed grouse	[5] 12	1.2	98.8	25.3	10.3		38.4	21.8			A. M. Leffingwell (*673*).
	[6] 80		100.0	[7] 14.2				78.6	7.3	7.9	Leon Kelso.[8]
	208	10.9	89.1	.9	11.8			48.1	28.3		S. D. Judd (*601*).
Prairie chicken	16	15.0	85.0	15.0				25.0	10.0		W. L. McAtee (*706*).
	17	28.0	72.0		27.2	5.9	13.9		18.7	6.0	Alfred Gross.[9]
Wild turkey	[10] 71	14.1	85.9	3.1	14.9		31.1	25.1	11.8		S. D. Judd (*601*).
	[11] 16	15.6	84.4	1.9	[12] 20.1	4.6		21.8	33.0		S. D. Judd (*601*).

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[1] Percentage of total gizzard contents.

[2] Crop contents studied during October to February.

[3] Some crops contained only a trace of grit, others contained as much as 15 percent.

[4] KELSO, LEON. FOOD FOR SCALED QUAIL, PRELIMINARY REPORT Bur. Biol. Survey Wildlife and Management Leaflet B. S. 84, 9 pp. 1937. [Mimeographed.]

[5] Crop contents studied during September, October, and November.

[6] Crop contents studied during winter months.

[7] A mixture of twigs, fruit, seeds, and flowers.

[8] KELSO, LEON. WINTER FOOD OF RUFFED GROUSE IN NEW YORK. Bur. Biol. Survey Wildlife Research and Management Leaflet B. S. 1, 3 pp. Rev. 1935. [Mimeographed.]

[9] GROSS, ALFRED O. PROGRESS REPORT OF THE WISCONSIN PRAIRIE CHICKEN INVESTIGATION. Wis. Conserv. Comm. 1930. [Typewritten.]

[10] Crop contents studied during October to April.

[11] Crop contents studied during February, March, July, September, November, and December.

[12] Contains small quantity of grain from 1 bird.

feed extensively upon these fruits. Likewise, bobwhites in the vicinity of a pine grove will gorge themselves on the pine mast.

Availability of the natural foods also has a marked influence on the food habits of birds. Drought, heavy snowstorms, and other weather conditions may have such an adverse effect on the supply of certain favored food material that the game may be forced to change their diet radically. For example, during a very severe winter, pheasants have been found with their crops stuffed with sumac berries, undoubtedly because there was a scarcity of more desired food material higher in nutritive value.

It will be noted from table 2 that upland game birds are primarily herbivorous. During a year, animal food constitutes only about one-sixth of the bobwhite's diet, one-ninth of the ruffed grouse's and the ring-necked pheasant's diets, and one thirty-third of the California quail's diet.

Influence of Age and Season

Game chicks are omnivorous, animal food predominating in their diet, especially during the first few weeks after hatching. Young California quail, for example, during the first week of life eat animal matter to the extent of 50 to 75 percent of their food, but after they are 4 weeks old they take little if any more animal food than the adult birds. Figure 3 illustrates this decrease and table 3 (*1105*) shows the selectivity of young quail as compared with adults.

TABLE 3.—*Principal foods contained in 154 crops and gizzards of adult bobwhites collected during the period that chicks are usually found afield (May 1 to November 1), and those contained in 34 crops and gizzards of chicks varying in age from 2 weeks to 3 months*

Article of food	Adults	Young	Article of food	Adults	Young
Animal food:			Vegetable food:	*Percent*	*Percent*
Grasshoppers and related insects	*Percent* 12.26	*Percent* 8.18	Fruit	30.85	16.78
Beetles	4.68	5.76	Grasses	18.77	36.12
Bugs	3.07	4.68	Legumes	5.30	4.97
Bees, wasps, ants, etc	52	24	Spurges	3.31	4.47
Miscellaneous insects		18	Cultivated plants (except legumes)	2.85	1.88
Caterpillars, moths, and eggs	1.62	3.85	Partridge-pea and other sennas	1.27	03
Spiders and related insects	47	82			
Slugs and snails		.70	Total	62.35	64.25
Miscellaneous animal matter	28	1.50			
Total	22.90	25.91			

The diet of any species varies considerably from month to month, as is shown in figure 4 for quails and figure 5 for pheasants.

During the summer when insects are available, the proportion of animal matter in the diet increases; harvesttime is a period of greater grain consumption; in the late fall weed seeds are a major article of diet; and winter brings increased nut consumption.

New Foods and Poisonous Foods

Stoddard (*1105*), in his work with the bobwhite, noted that the bird is very cautious about accepting new foods. While trapping quail for banding purposes, he used a mixture of several small grains as bait. The bobwhites were so attracted by the bait that they risked being trapped day after day to eat it. Two items of the grain mixture, how-

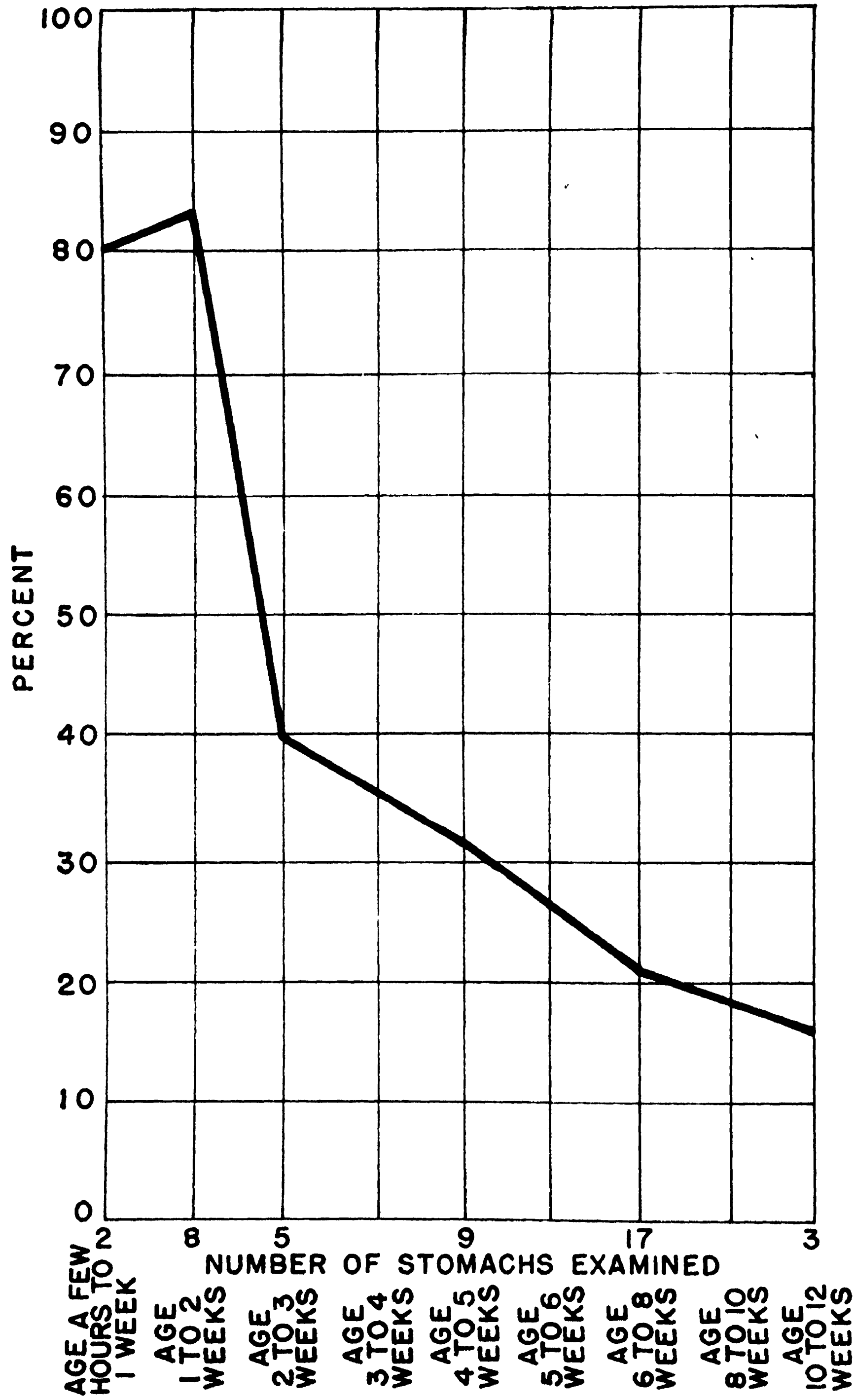

Figure 3.—Decreasing proportion of animal food in the diet of young bobwhites from week to week, based on examination of the contents of 54 crops and 44 gizzards. (From H. L. Stoddard's The Bobwhite Quail: Its Habits, Preservation and Increase, by permission of Charles Scribner's Sons, publishers.)

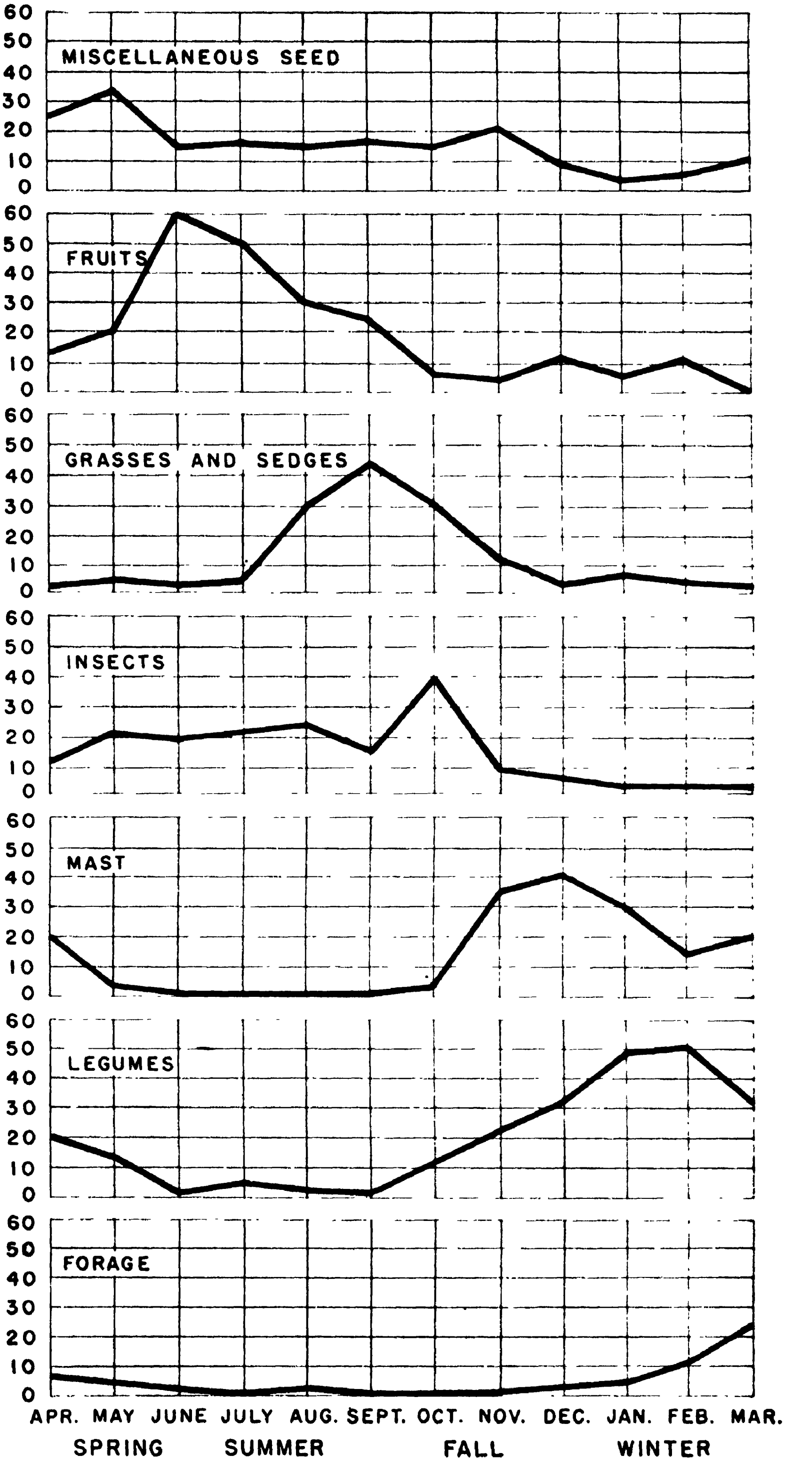

Figure 4. Variation in a quail's diet throughout the year. (From A. B. Massey (*764*), by permission of the author and the American Wildlife Institute.)

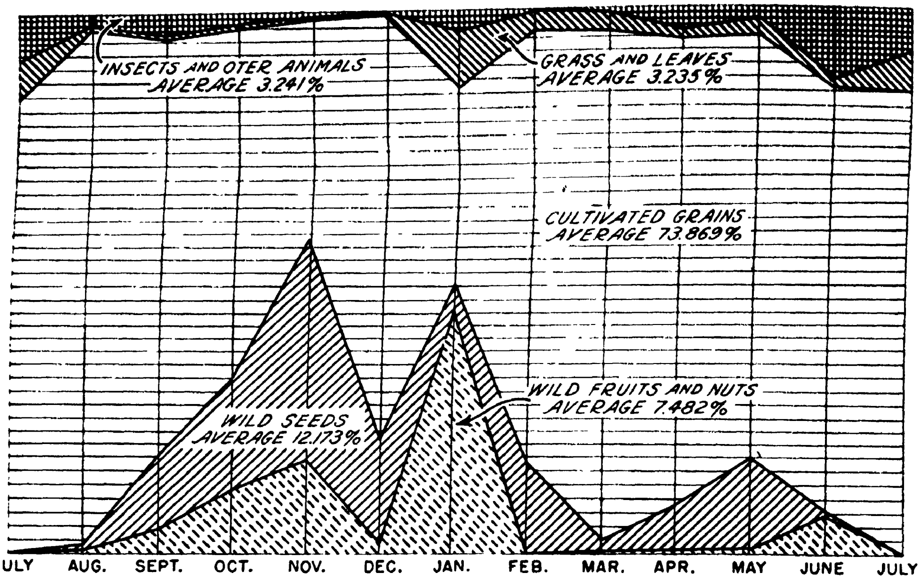

Figure 5.—Variation in a pheasant's diet throughout the year. (From P. L. Dalke (*248*), by permission of the author and the editor of Ecology.)

ever, buckwheat and upland rice, were left untouched. Both are considered good quail foods in areas where they have been grown and harvested over a period of years. Stoddard found also that Florida beggarweed, a favorite quail food in southern Georgia, was ignored by quail when used as a bait in a region where it is a rare plant.

The time required for game birds to become accustomed to a new feed may vary considerably. It has been noticed that feeding plots of soybeans or sorghum planted in a section for the first time may not be frequented until the second or third season. Then they will be occupied by three or four coveys of bobwhite almost simultaneously. On the other hand, bobwhite have been much attracted to fields of the gray winter pea during the first season that seed was matured.

There is conflicting evidence as to whether game birds tend to discriminate against poisonous food or not. Stoddard (*1105*), in his food study on bobwhite, found that even though the seeds of the coffeeweed (*Cassia tora*) are of an ideal size for quail and are very plentiful in rich soils of the Atlantic and Gulf Coastal Plains, they are avoided by quail. In an examination of the food material eaten by several hundred bobwhite, only one seed of the coffeeweed was found. Experimentation showed that this plant is highly poisonous to quail. When a healthy, vigorous cock was forcibly fed 250 of the seeds, he developed a severe diarrhea within several hours and was dead 2½ days from the time of the feeding.

This would indicate recognition of poisonous material, but McAtee points out a case where hundreds of pheasant chicks on the New Jersey Game Farm died of eating rose beetles, which contain a nerve poison affecting the heart action of certain species. In a letter quoted by Leopold (*677*), McAtee says:

> We doubt if there is anything resembling avoidance of poisonous food by wild life * * * The general rule regarding choice of food is that an animal takes what-

ever is most readily available, considering the size and degree of specialization in food habits * * * If something deleterious happens to occupy this position, so much the worse for the animal, but ordinarily this does not happen in a state of nature.

DESIRABILITY OF PROVIDING FEED PATCHES AND SHELTERS

Thousands of farms throughout the country are without sufficient food and cover to hold and support a good population of upland game birds throughout the winter months. Even where there is an abundance of wild foodstuffs, during late winter the supply may be exhausted or made inaccessible by ice and snow. The wildlife must either leave such localities for sections where food is obtainable or else face starvation.

Bobwhites are far less resistant to starvation than pheasants, and cannot be deprived of substantial food for more than a few days at a time without danger. A food crisis that lasts a week may cause heavy mortality, and one of 2 weeks' duration may practically annihilate populations over wide areas.

Figure 6.—An eroded hillside. Soil losses are often hastened by pasturing livestock on such vegetation as can grow under uncontrolled conditions.

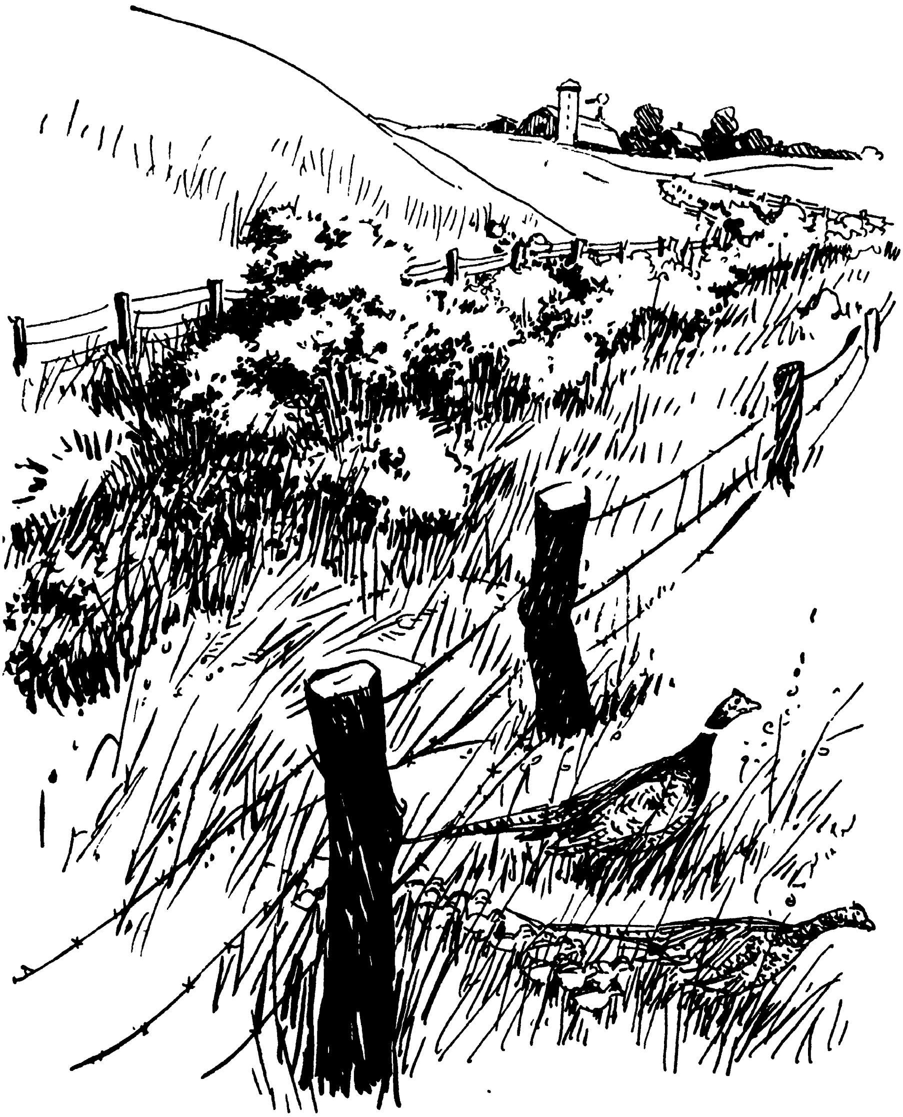

Figure 7.—What could be done with the hillside shown in figure 6 by conserving soil through suitable plantings and fencing out cattle, sheep, and hogs. In the resulting cover, game can find a suitable habitat for nesting and feeding.

If farmers do not wish the depletion of game from their farms, they must provide food on the home range during the season of shortage. This may be done by planting food patches, and by the establishment of feeding stations during emergency periods.

Few farms are wholly free from eroded or rough land unsuitable for cultivation. These waste areas are usually made totally barren by pasturing livestock on them. If natural vegetation were allowed to grow in such places, erosion and gullying would be stopped, and at the same time cover and food would be supplied to game (figs. 6 and 7.) The farmer could assist nature by judicious planning and the planting of grasses, legumes, trees, shrubs, vines, and other erosion-resisting vegetation (*261*).

Most State game commissions, the Bureau of Biological Survey, or the Soil Conservation Service are willing to assist the farmer in such projects.

Size, Location, and Crops for Feed Patches

Feed patches are often maintained on cultivated land. These may vary in size from a fourth of an acre to several acres in extent. Under highly intensified agriculture, most farmers do not care to devote a large acreage to the supplementary wildlife food crops. It is of importance, therefore, that the plant selected for the food patch ranks high in its ability to produce heavy yields. A number of sorghums, Sudan grass, Minnesota sorghum, flax, sunflower, millets, buckwheat, and corn are such plants. In regions of severe winter weather, wheat, oats, barley, or buckwheat are not very effective, as they have weak stalks, incapable of holding the head of grain above the ice and snow. Thus their usefulness is limited to the fall and early winter months.

Experience indicates that corn is by far the most important patch food. R. G. Hill of Michigan (*513*) points out that—

> a small patch of corn planted adjacent to permanent winter cover or near a patch of rye or sweetclover seems to fulfill the winter food requirements of most of our wildlife species which occur on the farm. An early maturing variety of yellow dent corn, such as Golden Glow, may be planted and cultivated at least two or three times, or a sufficient number of times to insure a good crop of ears The crop should be planted and cared for the same as the regular crop grown for grain production. If cover is limited in the vicinity of the food patch, it is well to omit the last cultivation and allow weeds to grow and form a dense mat of ground cover.

Corn is also outstanding for its resistance to shattering. Fry (*400*) points out that Gordon in 1937 found yellow dent corn to be the most palatable of 10 grains used in his observational food patches. The preference rating was as follows: 1, Yellow corn; 2, squaw corn; 3, soybeans; 4, German millet; 5, Siberian millet; 6, Japanese millet; 7, wheatland milo; 8, Greeley kafir; 9, Darso sorghum; 10, Minnesota sorghum.

RECOMMENDATIONS FOR SHELTERS AND FEED STATIONS

Permanent shelters where grain can be placed make good winter feeding stations for game birds. These shelters should be built close to good protective cover, in areas that are protected from drifting snow, sleet, and wind. Sufficient openings should be left so that birds can easily escape from predators (fig. 8).

Stations should be started by November 5 or not later than December 1, so that the birds will know their location and establish them within their regular daily feeding range. They must be visited regularly by the attendant, and provisions must be made for an adequate supply of grain. A few corn shocks provide the simplest yet probably one of the best types of stations which can be established.

According to Grange (*432*), in areas where bobwhite or Hungarian partridge are abundant, one feeding station to every 40 acres is desirable; otherwise, a station may be built near the thicket that a covey is known to use. For ring-necked pheasants, one effective station

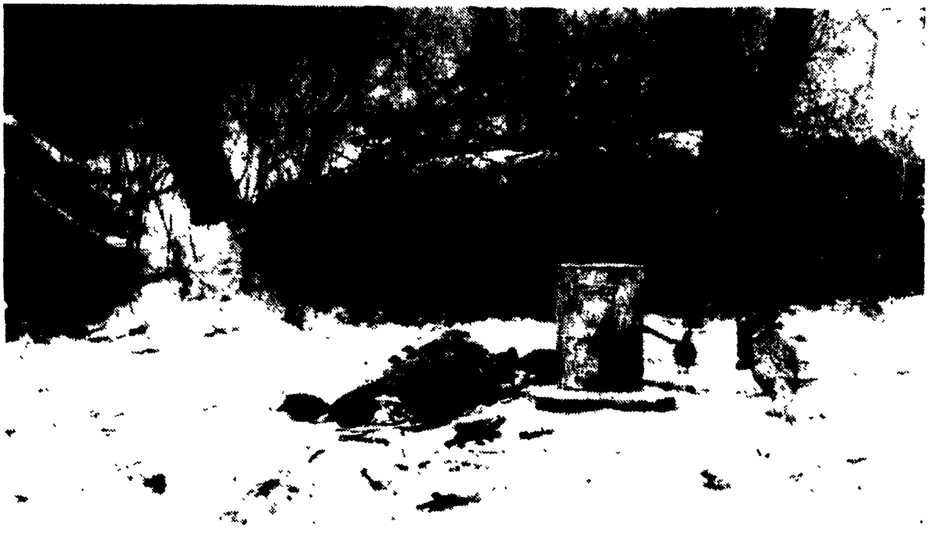

Figure 8.—Bird feeding station maintained by the Minnesota State Conservation Department during the winter of 1931–32, where more than 200 pheasants and 42 quail were fed. The feeder in the center was a home-made device that kept a constant supply of seed before the birds.

per square mile is sufficient for feeding; and for prairie chickens, one every 5 or 10 square miles is satisfactory. Although wild turkeys will come from considerable distances, it is best to provide feed in all the permanent winter headquarters that they are known to frequent. For ruffed grouse there is very little that can be done in the way of emergency feeding. In the wild this species subsists primarily on browse and fruits, and although they relish grains in captivity they are slow in learning to accept this diet in the wild. Workers in Wisconsin (*211*) estimate that the approximate quantity of grain needed to maintain one game bird a week in severe winter weather in addition to the wild food that may be picked up is as follows: Pheasants, 2 pounds; prairie chickens, 1 pound; Hungarian partridge, ¾ pound; quail, ½ pound.

In emergencies, feeding may be done wherever birds are found, including ditches, hard packed roads, haystacks, railroad rights-of-way, or any natural windbreak or shelter. The important thing is that the feed must be placed where the birds will find it.

NUTRITION OF GAME BIRDS UNDER CONTROLLED CONDITIONS

In the endeavor to replenish the supply of game birds, artificial propagation of certain species, especially ring-necked pheasants and the bobwhite, is becoming a promising business in certain sections of the country. The changes in methods of incubation, brooding, and feeding have been quite radical in recent years, indicating the transition of the business from the pioneer stage to a more substantial basis. For example, 23 years ago, Oldys (*871*) gave the following information to pheasant breeders regarding the feeding of pheasant chicks:

> Young pheasants pick up many insects in the rearing field, but the supply must be supplemented. It is customary to depend on so-called ants' eggs (really the

pupae of ants), maggots, mealworms, or finely ground meat . . . Mealworms are very satisfactory, but are difficult to raise in sufficient quantity. Maggots are equally good, and enough can be produced cheaply. The customary method is to suspend a piece of meat, or the carcass of a dead animal, over a barrel or tub of bran. The flesh becomes flyblown and the maggots drop into the bran. Before they are used the maggots must be thoroughly cleansed or they are apt to cause purging. This is usually done by putting burlap or very fine wire in place of the bottom of the barrel or box of bran. They will work their way through the bran in search of food and may be caught in a receptacle below, all ready for feeding to the pheasants. This method is very offensive, and may be replaced by permitting a carcass to become flyblown and then burying it a few inches in the ground; the maggots will work their way to the surface where they can be secured by the young pheasants.

To the untiring perseverance of the pioneer game breeders in their endeavor to improve the methods of propagation belongs the credit for the remarkable advance in feeding methods since Oldys' day. Research men in some of the State agricultural experiment stations have recently initiated studies in game nutrition. Notable among these are workers at Cornell University, Pennsylvania State College, Michigan State College, and Wisconsin University. The Federal Government, through the Bureau of Animal Industry of the Department of Agriculture and the Bureau of Biological Survey, also is planning research in this new field.

NUTRITIONAL REQUIREMENTS OF GAME BIRDS

Like human beings and domesticated animals, game birds require a balanced diet for proper growth, maintenance, and reproduction. If there is a good choice of food materials available, the bird in the wild state will balance its diet successfully. In the captive state, however, the bird must depend wholly upon man to furnish it with sufficient quantities of the necessary nutrients.

Water

First, water is essential. Even though game birds in the wild seem to manage well on dewdrops and succulent material, in confinement they require a more reliable source of water. Approximately 56 percent of a chicken's body and 72.5 percent of the egg contents is water. Water ranks far above any other substance in rate of turn-over in the body. It serves to soften the feed, aids in the processes of digestion and absorption of other nutrients, serves in transporting the end products of digestion from the digestive tract to various parts of the body, and assists in the elimination of waste products. Water also facilitates cell reactions, helps to regulate body temperature, aids in the lubricating of the joints, and acts as a water cushion for the nervous system.

Seeds

Seeds and their byproducts have a very important place in the diet of birds. For the feeding of birds in confinement, cereals are used instead of most of the seeds obtained by birds in the wild, because of their availability and comparative low cost. This feed material is considered valuable primarily because its carbohydrate content supplies the fuel for the body heat and is the principal source of energy. The grains also add bulkiness to the diet. There is some evidence that the presence of a small quantity of indigestible and somewhat bulky material in the intestines facilitates both the digestion and absorption of the digestible portion.

Other valuable properties possessed by the cereal foods are seldom considered by the average person. Cereal grains and their byproducts are the chief sources of vitamin B_1 (thiamin) and vitamin E in a typical diet for birds. Vitamin B_1 is essential for growth, maintenance of appetite, and the prevention of polyneuritis; vitamin E is vital for the production and hatchability of eggs. Certain cereal byproducts, such as rice bran and wheat middlings, have also been found comparatively high in manganese, which is very necessary in the prevention of perosis or slipped tendon. Yellow corn is prized as a fair source of vitamin A. Oats and their byproducts hold a special place among grains. Titus has pointed out that they are a good source of the anti-gizzard-erosion factor; they tend to prevent rancidity when finely ground and thus are valuable in the preservation of vitamins A and E; there is good indication that they tend to prevent a fishy flavor in a bird's flesh when cod-liver oil is fed; and they are reputed to be of high value in the prevention of cannibalism, toe picking, and feather picking. An intense study of this last characteristic has been made by Miller and Bearse of West Washington Experiment Station (*789*).

Norris (*856*) in his work with pheasants found that wheat flour middlings when used as a large portion of the diet had definite perosis-preventing properties and promoted fair growth and good feathering. He noted, however, that the perosis-preventive property may vary considerably.

Very little work has been done on the value of the various cereals in the diet of game species. J. B. Coleman, pioneer bobwhite breeder in Virginia, conducted an interesting experiment on his farm, in which he placed more than a score of seeds, including legumes as well as cereals, in separate containers, and studied the birds' selection. To his amazement, the birds practically avoided the legume seeds, which are found in large quantities in the crops of wild birds, and showed a marked preference for kafir and the millets. According to Coleman, rye, which is not a palatable feed for chickens, was eaten by the bobwhite to as great an extent as oats, wheat, and barley, without causing any apparent digestive disorders.

In similar work conducted in Wisconsin by Hawkins, Moore, and Leopold (*211*), it was found that game birds like corn better than any other grain. The percentage of the other seeds consumed by the time all the corn was exhausted gives a good idea of how the feeds compare in palatability:

	Percent		*Percent*
Wheat and scratch feed	50	Sweet corn and Sudan grass seed	35
Buckwheat	45	Sorghum seed	25
White corn, popcorn, and barley	40	Soybeans, oats, and rye	15

At Missouri University, Nagel (*834*) made an interesting study on the relationship between diet and extent of parasitism in the bobwhite. From his data he drew the tentative conclusion "that the presence of sorghum cane in the diet of bobwhite quail has a restraining effect on parasitism."

Protein Concentrates

Proteins are indispensable constituents of the blood, muscles, organs, skin, tendons, bone, and feathers, in fact, of all tissues of the animal body. They constitute about one-fifth of the live weight of a chicken and between one-eighth and one-seventh of the whole egg. Although some protein is derived from the cereals and green foods, the primary source is protein concentrates. There are two classes of these concentrates, namely, those obtained from animal sources, such as dried skim milk, meat meal, and fish meal, and those obtained from plant sources, such as soybean meal, linseed meal, and peanut meal.

Practically no work has been done on the comparative value of the various protein concentrates in the nutrition of game birds. The Pennsylvania workers (*185*) in 1933 believed that the use of ordinary commercial (55-percent protein) meat and fish meal in a high-protein mash permitted the development of an appreciable percentage of perosis cases, and recommended a meat scrap of a higher protein content (75 percent).

Norris (*859*) of Cornell sought to determine the relative importance of dried skim milk, fish meal, and meat scrap in the best pheasant chick ration developed so far. These ingredients were progressively removed from the ration, first one at a time, then two at a time, and finally all three. He found that all three played an important part in balancing the diet, but his results did not clearly reveal the cause of the better balance attained. He has formulated pheasant diets in which he has included a mixture of soybean meal, vacuum- or steam-dried fish meal (60- to 65-percent protein), meat meal (75-percent protein), and dried skim milk. Apparently these diets have proved successful in pheasant production.

Notable work has been done on the quantitative protein requirements of pheasants and, to a lesser extent, of bobwhite. In 1932, Callenbach, Murphy, and Hiller (*186*) pointed out that better early growth of pheasants was obtained on a diet containing a higher level of protein than is suitable for the domestic chick. The best growth and feathering and greatest feed consumption per 100 pheasants were secured through the use of a diet analyzing approximately 28 percent of protein.

Beginning the same year, Norris and associates of Cornell University, in cooperation with Bump of the New York State Department of Conservation (*860*), began a series of experiments to compare the effects on pheasants of diets containing the following proportions of protein—18, 21, 24, 27, 30, and 33 percent. The chicks were started on the diets approximately 24 hours after hatching and the experiment was continued for 18 weeks. After three different experiments it was concluded that a diet containing 24 percent of protein is necessary for rapid early growth of pheasants. This is about 4 percent more than the requirement of chickens. The maximum growth of pheasants was attained at 27 percent, while levels of 15 and 18 percent significantly retarded growth and cannibalism and feather pulling were also more prevalent at these low-protein levels. The results of their third experiment are given in table 4.

In his study on the protein requirements of bobwhite chicks, Norris in New York (*856*) used protein levels of 21, 24, 27, 30, 33, and 36 percent on battery-reared birds. Two experiments showed that the bobwhite requires 27 percent of protein in its diet for rapid growth. However, the difference between the results at the 24-percent and the 27-percent level was not great.

TABLE 4.—*Weight of pheasant chicks at 4 and 8 weeks on six different levels of protein*

Protein in ration (percent)	Average weight [1]			Protein in ration (percent)	Average weight [1]		
	Initial	At 4 weeks	At 8 weeks		Initial	At 4 weeks	At 8 weeks
	Grams	*Grams*	*Grams*		*Grams*	*Grams*	*Grams*
18	18.7	116.8	358.3	27	18.0	153.0	444.4
21	18.5	136.3	418.6	30	18.3	149.0	451.7
24	18.7	157.5	454.3	33	18.9	155.0	463.2

[1] Weighted for sex influence.

An analysis of Coleman's quail feeds at the Poultry Nutrition Laboratory, Agricultural Research Center, reveals the following proximate protein content: Quail mash, 28.36 percent; chick seed-grain mixture, 14.02 percent; adult seed-grain mixture, 12.76 percent.

Vitamins

Vitamin A

Vitamin A is essential for growth, reproduction, hatchability, and maintenance of health. It is found chiefly in materials of animal origin, such as livers of both mammals and fish, and in fish-body oils. Cod-liver oil, when properly prepared and stored, is a very rich source of this factor, containing from 272,150 to about 1,000,000 International Units per pound. Sardine oil contains about 13.5 percent as much of this vitamin as cod-liver oil.

Plant materials are the chief sources of vitamin A precursors—the substances that are changed to vitamin A in the animal body—of which carotene is the most common. Such green foods as fresh alfalfa, kale, and clover are excellent carriers. If alfalfa or clover is properly dried and stored, it retains a great deal of the carotene.

Oxidation and heat readily destroy both vitamin A and its precursors. Because of this fact, cod-liver oil should be kept in closed, well-filled receptacles in a cool place, and should not be mixed with feed until a short time before it is to be used. Likewise, corn and alfalfa products should not be stored for long periods, for it has been found that in 1 year 50 percent or more of the carotene is lost. In hot weather these ingredients should be kept in a cool place. A bright-green alfalfa-leaf meal is preferable to brownish-green meal, but the color is not an absolute criterion of the vitamin content. No work on the vitamin A requirements of game birds has been recorded in the literature.

Vitamin B_1 (Thiamin)

As was pointed out in the section on cereals, the ordinary diet, in which grains predominate, usually contains sufficient quantities of vitamin B_1 (thiamin) for animal maintenance. This is true for some game birds as well as for chickens. The workers at Cornell (*856*) found that the quantity of vitamin B_1 needed by young pheasant chicks is easily supplied by common cereals and their byproducts. However, in their work with ruffed grouse, they noted symptoms of vitamin B_1, deficiency among the birds used in the 1932 experiment and corrected them by the use of a vitamin B_1 extract.

Vitamin D

Vitamin D is required for the development of a normal skeleton and for reproduction. Too much vitamin D, that is five or six times the quantity normally required, is as deleterious as too little. This factor is not found in the ordinary foodstuffs. For animals living in the open, this vitamin is manufactured in the body by the action of the ultraviolet rays of the sun upon certain vitamin D precursors, such as cholesterol and ergosterol, present in the system. But when birds are raised and maintained under artificial conditions, another source of this factor must be used. Fish oils, such as cod-liver and sardine, are the best sources known at present. The vitamin D content of cod-liver oil ranges from 38,590 to about 160,000 International Units per pound.

Baird and Greene (*54*) found that pheasants require a minimum of approximately 225 to 275 International Units of vitamin D per pound of feed in an otherwise balanced diet.

Norris (*859*) reports further investigations of the vitamin D requirement of pheasant chicks by F. D. Baird, which showed that 0.25 percent of fortified cod-liver oil containing 113,398 International Units of vitamin D per pound prevented the development of rickets during a test period of 8 weeks. This is about three times as much of the same oil as was found necessary to prevent a rachitic condition in domestic chicks fed a similar rickets-producing diet. Norris' results are given in table 5.

TABLE 5.—*Average weight, percent of bone ash, and bone structure of 8-week-old pheasant chicks fed eight different levels of fortified cod-liver oil*

Fortified cod-liver oil (percent)	Average weight at 8 weeks	Average amount of bone ash at 8 weeks	Average bone structure at 8 weeks	Fortified cod-liver oil (percent)	Average weight at 8 weeks	Average amount of bone ash at 8 weeks	Average bone structure at 8 weeks
	Grams	*Percent*			*Grams*	*Percent*	
0.00	(1)			0.20	356.0	39.1	Slightly rachitic.
0.05	(1)			0.25	408.1	46.9	Normal.
0.10	220.0	34.5	Rachitic.	0.30	359.7	47.4	Do.
0.15	211.5	37.6	Do.	0.35	389.0	45.7	Do.

All dead.

Vitamin E

Vitamin E is necessary for reproduction and hatchability of eggs. Green foods, such as alfalfa and clover, and the germs of grain are the best known sources of this factor, although it has been found widely distributed in nature. Under ordinary conditions, vitamin E is quite stable, but it is very quickly destroyed by rancidity. For this reason, feeds that are rancid, even very slightly, should never be used.

Vitamin G (Riboflavin)

Vitamin G is another factor essential for growth and for hatchability of eggs. Dried whey, yeast, dried skim milk, and liver are especially rich in it, and green foods are very good sources. Alfalfa-leaf meal from plants that have been properly harvested and cured contain more of this factor than the green alfalfa. Protein concentrates from animal products are fair sources, but the grains contain relatively little.

Studies by the Cornell workers (*859*) on the need of pheasants for vitamin G during early growth indicate that this is satisfied by the inclusion in the diet of 4 percent of dried pork liver, which is equivalent to about 20 percent of dried skim milk. This is 2 to 2.5 times greater than the requirement of domestic chicks for this factor. The results of these studies are given in table 6.

TABLE 6.—*Average weight of pheasant chicks at 4 and 6 weeks old fed diets containing eight different amounts of dried liver for the vitamin G content*

Dried liver in diet (percent)	Average[1] weight			Dried liver in diet (percent)	Average[1] weight		
	Initial	At 4 weeks	At 6 weeks		Initial	At 4 weeks	At 6 weeks
	Grams	*Grams*	*Grams*		*Grams*	*Grams*	*Grams*
0	18. 7	48. 8	102. 0	4	18. 8	130. 4	238. 2
1	18. 5	86. 3	162. 2	5	19. 9	142. 6	262. 5
2	18. 8	110. 8	203. 9	6	19. 2	151. 0	281. 9
3	18. 7	119. 5	228. 2	7	18. 1	146. 9	274. 9

[1] Weighted for sex influence.

Other Vitamins

Although present investigations indicate that the ordinary domestic chicken synthesizes sufficient vitamin C for its needs, nothing is known about the requirements of game birds for this factor. Other less known vitamins, such as the factors that seem to prevent chick dermatitis, encephalomalacia (a brain disorder due to a nutritional deficiency), hemorrhage, and gizzard erosions are still too new in the knowledge of domestic-poultry nutrition to have received much consideration in studies on game-bird nutrition.

Minerals

Calcium, phosphorus, manganese, sodium, potassium, magnesium, sulfur, chlorine, iron, iodine, copper, zinc, and silicon are all known to be necessary for the maintenance of life and reproduction, and possibly cobalt should be included in this list. Many of these elements are found in the ordinary foodstuffs in adequate quantities to meet the animal's needs. However, there are certain ones, such as sodium, chlorine, calcium, phosphorus, and manganese, that may have to be be supplied as supplementary material.

Sodium and Chlorine

Sodium is very necessary for the maintenance of the acid-base equilibrium of the body, and chlorine is an important constituent of the digestive juices. As a rule, both may be furnished through the medium of common salt. For the domestic fowl 0.5 percent of salt in the chick diet and 0.7 percent in the mature-stock diet has usually been found sufficient. Norris (*859*) in his suggested pheasant-chick diet uses 0.5 percent of salt.

Calcium and Phosphorus

Calcium is one of the main elements involved in skeletal and eggshell formation. It may be furnished to birds in the form of high-grade limestone, oystershell, or crab shell, all of which are very good sources. Phosphorus works together with calcium in the metabolic processes of the body. It, too, is a characteristic constituent of the bones. An excess of either or both of these elements is to be avoided, since it has been found that an excess of inorganic phosphorus will considerably increase the incidence of perosis in domestic chicks. Usually for growing birds there is sufficient phosphorus in the diet without any being added, but for laying stock it is sometimes necessary to supply extra phosphorus. When calcium and phosphorus are both required, steam bonemeal is fed as a part of the diet.

Callenbach and Murphy of Pennsylvania State College in 1935 experimented with ring-necked pheasant chicks kept in battery brooders (data unpublished). These birds were fed diets in which the calcium content varied from 0.5 to 3 percent and the quantity of phosphorus ranged from 0.5 to 1 percent. The calcium-phosphorus ratio varied from 1:1 to 3:1. Their results indicated that for pheasants reared in batteries a diet containing 1.50 percent of calcium and 0.75 percent of phosphorus gives satisfactory growth and sound bone development.

In very recent preliminary work by Skogland, also of Pennsylvania State College, six diets were used, the calculated calcium and phosphorus contents of which are given in table 7.

TABLE 7.—*Calculated calcium and phosphorus contents of diets fed pheasant chicks at Pennsylvania State College*

Diet No.	Calcium	Phosphorus	Calcium-phosphorus ratio	Diet No.	Calcium	Phosphorus	Calcium-phosphorus ratio
	Percent	*Percent*			*Percent*	*Percent*	
1	0.72	0.73	1.0:1.0	4	2.00	1.00	2.0:1.0
2	1.00	1.00	1.0:1.0	5	2.50	1.00	2.5:1.0
3	1.50	1.00	1.5:1.0	6	2.50	1.25	2.0:1.0

The birds on diet No. 1, which contained 0.72 percent of calcium and 0.73 percent of phosphorus, showed the best growth, consumed the smallest quantity of feed, made the most efficient use of the feed consumed, had the lowest mortality, and experienced the least occurrence of perosis. On the other hand, the birds on diet No. 4, which contained 2 percent of calcium and 1 percent of phosphorus, showed the poorest growth, consumed the largest quantity of feed, rated fifth in feed consumption and efficiency, had the highest mortality, and experienced the greatest and most severe occurrence of perosis.

In Norris' suggested pheasant diets for growing birds the calcium content is kept at 1.6–1.7 percent, and the phosphorus content at 0.8–0.85 percent.

So far as is known, no work has been done on the calcium and phosphorus requirements of mature game birds.

Manganese

Very recent nutritional studies with chickens have disclosed the fact that manganese deficiency and perosis are definitely linked together. Although perosis is apparently the result of a complexity of factors, the addition of manganese to a perosis-producing diet will decrease the malady considerably, if not eliminate it entirely, especially if the percentage of phosphorus is kept at a low level. Chickens require at least 50 parts per million of manganese in the diet. In the case of this species, Titus advises the addition of 1.7 pounds of anhydrous manganous sulphate or 2.5 pounds of manganous sulfate tetrahydrate to 100 pounds of common salt, for mixing with the diet. In the mineral studies conducted by the workers at Pennsylvania State College, there were between 36 and 40 parts per million of manganese to each diet. Perosis was prevalent throughout the experiment, and even with the diet containing only 0.73 percent of phosphorus, there was one case of the malady. Bass (*64*), in his work with the bobwhite, is convinced that 40 to 100 parts per million of manganese in the diet will prevent perosis.

Other Minerals

The value of the addition of other minerals to the diet is doubtful. Recent work with chickens indicates that the addition of potassium iodide, iron compounds, copper compounds, and possibly sulfur to the diet of that species may be of value at times. The last-named material has little nutritional value, but may be of some use in combating coccidiosis, an avian disease affecting the digestive tract, especially the ceca.

Although charcoal is used quite extensively by wild-game breeders, it has little, if any, value nutritionally.

Grit

Work by poultry nutrition workers at the Agricultural Research Center has shown that gallinaceous birds can live without grit and even digest whole grain without its aid. When grit is present, however, there is more efficient utilization of feed, and less energy is required by the gizzard for grinding feed. In the case of growing domestic chickens abscesses may occur in the gizzard lining if a finely ground, low-fiber diet is fed without grit.

Leopold (*677*) points out that most game birds in the wild consume grit daily, pheasants particularly frequenting graveled roads at nightfall, presumably for this purpose.

Titus is convinced that "it is a worth-while practice to supply grit to chickens so reared and kept that they do not have access to the soil." However, he points out that it is highly important that careful consideration be given to the kind of grit that is supplied. Probably the best grit one can obtain is river gravel or native pebbles, but any insoluble, nonfriable rock material may be used. Fine sand is of no value as grit because it readily passes through the gizzard, but very coarse sand may be used for young birds.

DIET FORMULAS

Because of the paucity of knowledge concerning the nutrition of game, there are very few recommended game diets.

Norris (*859*) suggests two diets for young pheasants on the basis of experimental results and practical experiments (table 8).

TABLE 8.—*Composition of two diets for young pheasants*

Ingredient	Diet No. 1	Diet No. 2
	Percent	*Percent*
Yellow corn meal	20.0	24.0
Wheat-flour middlings	25.0	25.0
Ground heavy oats	10.0	10.0
Dehydrated alfalfa meal (20 percent protein)	5.0	5.0
Dried skim milk	20.0	10.0
Dried liver	—	2.5
Meat meal (75 percent protein)	5.0	5.0
Fish meal (60 to 65 percent protein), either vacuum- or steam-dried	5.0	5.0
Soybean meal	6.5	10.0
Pulverized limestone	2.0	2.0
Common salt	0.5	0.5
Cod-liver oil (85 International Units of vitamin D per gram)	1.0	1.0
Total	100.0	100.0

Articles in this Yearbook by H. W. Titus on the nutrition of the domestic chicken, entitled "Practical Nutritive Requirements of Poultry" and "Practical Feeding of Poultry," give information on the nutrition of domestic gallinaceous birds that may be applicable to the upland game birds. In the last-named article are some valuable tables on the composition of foodstuffs, including the mineral and vitamin content, and their digestibility.

FEEDING PRACTICES

There have been two notable changes in the management practices of propagators of upland game birds: (1) From rearing and maintaining the birds on the ground to rearing and maintaining them on wire cloth (fig. 9, *A*); (2) from the custard-clabber feeding of game chicks to a more simplified and sanitary system of feeding (fig. 9, *B*).

Until very recently, all breeders gave their chicks and mature birds access to runs planted to some cover crop such as clover, alfalfa, cereals, or grass. However, whatever benefits were derived from the green feed were nullified by the spread of disease, especially ulcerative enteritis or "quail disease," from the contaminated ground. Regarding this disease, Stoddard quotes from Dr. Morse:

> At the beginning of an outbreak the more susceptible birds may die suddenly without showing noticeable symptoms or the characteristic internal lesions. Less acute cases show ruffled feathers, dullness, droopiness, lack of appetite, increased thirst, and frequently diarrhea . . . In chronic cases emaciation is extreme . . . The most characteristic lesions are numerous small, yellowish areas of necrosis in the wall of the intestine. These areas average about the size of a pinhead and may be seen through the peritoneal surface. Necrotic ulcers sometimes perforate the intestinal wall.

Propagators of bobwhite and ruffed grouse have found that such contagion can be reduced considerably by rearing the young stock and maintaining the breeders on sun porches of wire cloth rather than on restricted range (fig. 10, *A* and *B;* fig. 11, *A* and *B*). They supply freshly cut green feed taken from nearby grass plots every day in special receptacles.

The making of custard for game chicks is a laborious, unnecessary procedure that is rapidly losing favor with breeders, while clabber is apt to bring about parasitic infestation of birds by drawing hundreds of flies that are carriers of disease germs.

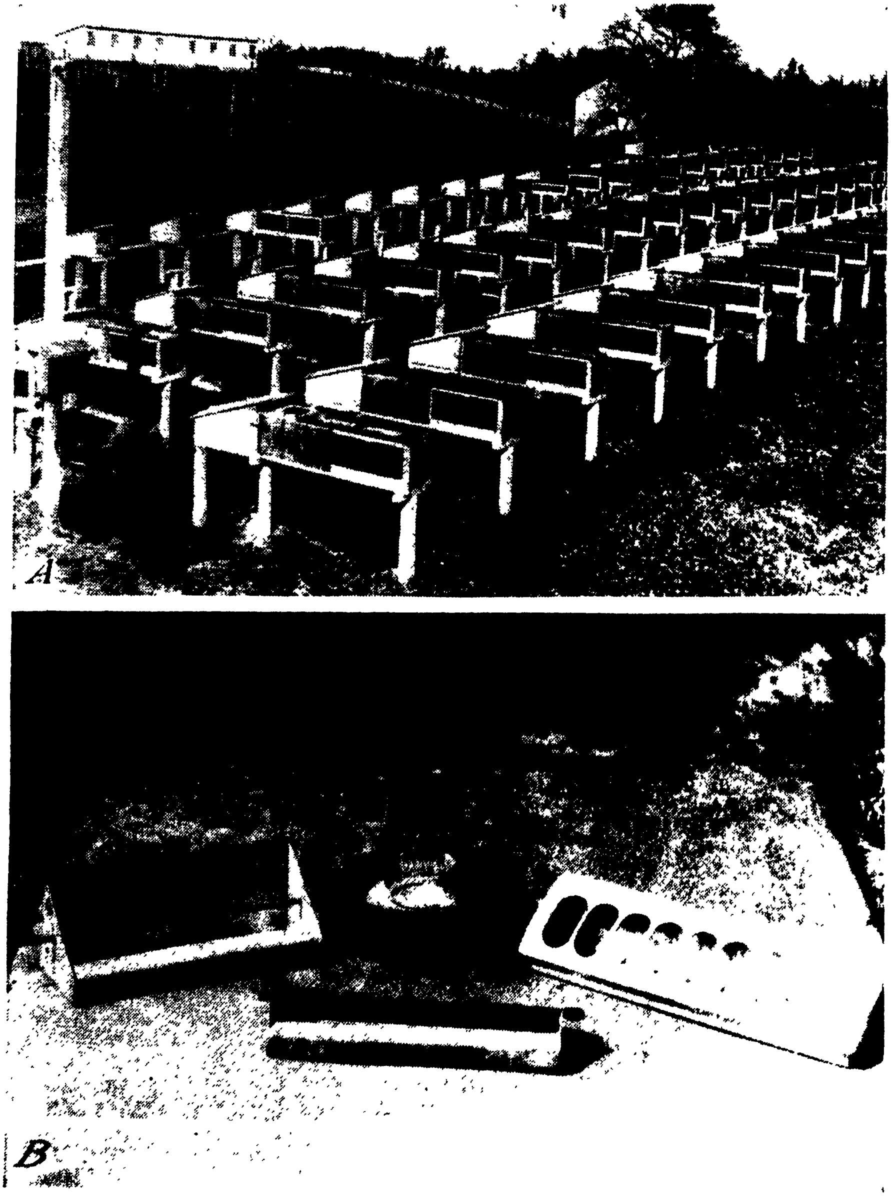

Figure 9.—**A,** Modern electrically heated quail brooder pens in Maryland. These pens will hold 15 to 30 quail chicks; **B,** quail feeding and watering devices.

Feeding Chicks

Pheasants

Smith (*1066*) reports the procedure that is used successfully with pheasants on the Fisher State Game Farm in Pennsylvania as follows:

> The chicks are fed the first 3 days on our 30 percent pheasant starting mash, with a little fine sand mixed in and water. At 6 and 10 a. m., and at 2 and 6 p. m., they are fed sparingly on fine hard-boiled egg sprinkled on mash, to teach them to pick the mash. Three times daily they are given fine chopped greens. On the fifth day we add fine grit, oyster shell, and charcoal. At 3 weeks they are started on fine chick grain mixed with the mash, and at 5 weeks intermediate scratch is given.

Unfortunately Smith does not disclose the formula of their mash.

Additional feeding facts are given by the Pennsylvania Board of Game Commissioners.[5] They warn: "Do not overfeed. Just give the birds enough for them to clean up in 10 or 15 minutes." They also state:

> Starting the seventh week, begin feeding in rainproof hoppers a high grade growing mash. This change of feed must be made gradually by mixing the growing mash with the starter for a few days, before feeding the straight growing mash. In addition, feed a medium scratch grain every evening. On this ration you may raise your birds to maturity.

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[5] ANONYMOUS. HATCHING AND REARING RINGNECK PHEASANTS. Pa. Board of Game Commrs., Div. Propagation and Game Farms Rept. 1936. [Mimeographed.]

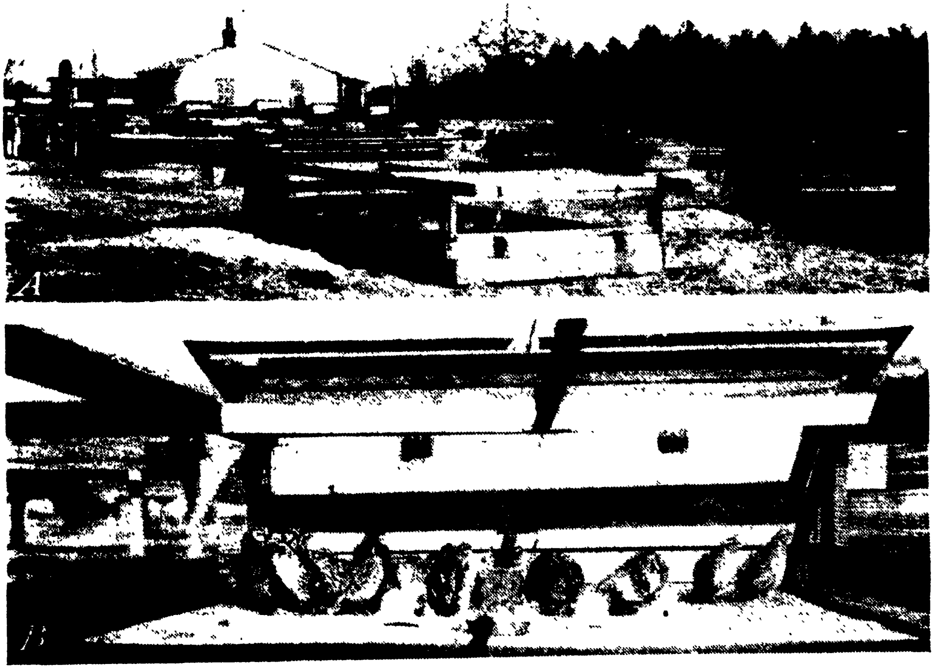

Figure 10.—*A*, and *B*, Bobwhite quail in winter holding pen, Petersburg, Va., February 1939. (Courtesy of James Schwenck.)

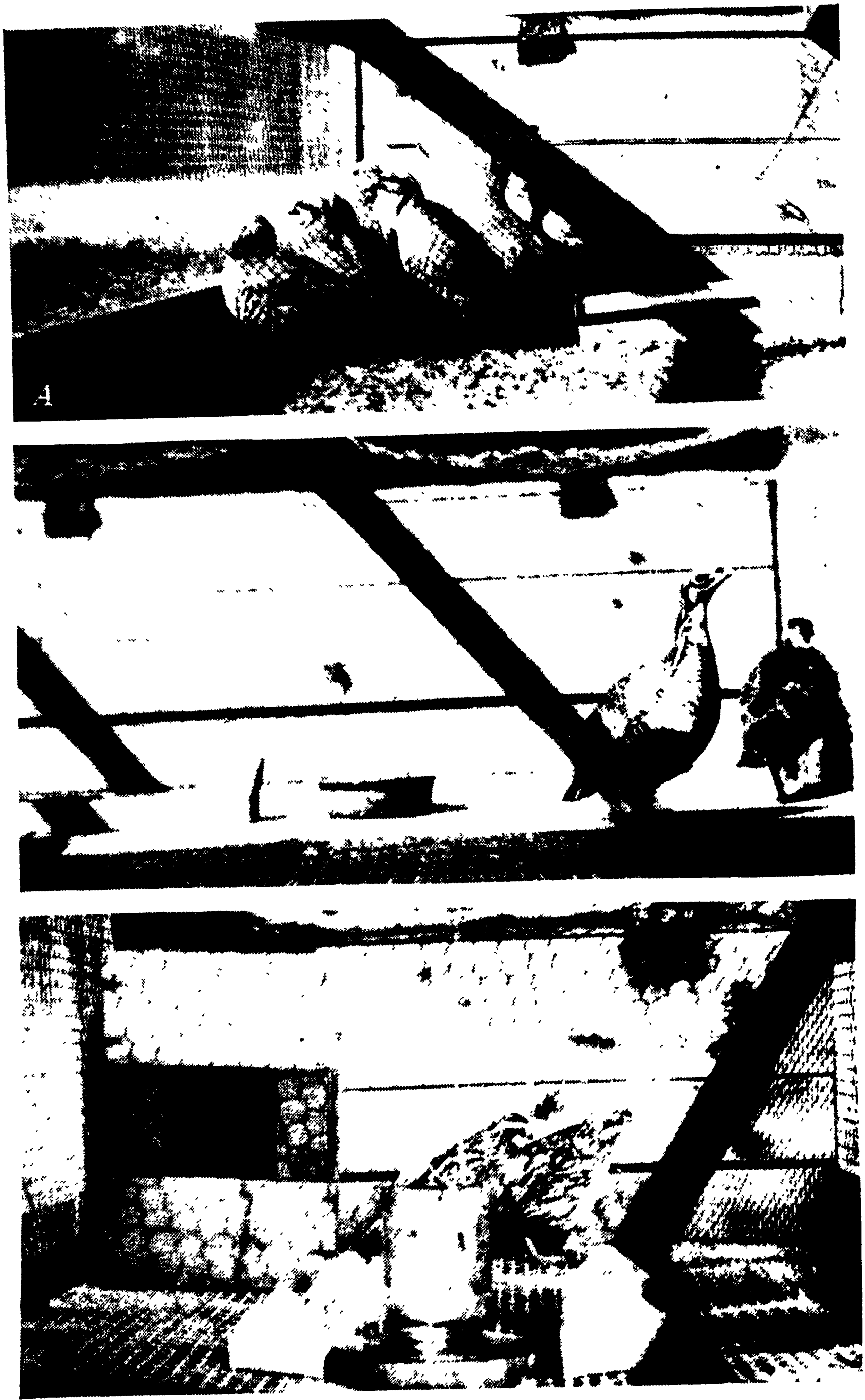

Figure 11.—*A*, Chukar partridges in winter holding pen. No difficulties have been encountered in maintaining chukars on the ground. *B*, Prairie chickens in winter holding pen, Richmond, Va., February 1939. (Courtesy of W. B. Coleman.) *C*, Male and female bobwhites in laying pen; nest, feeders, and waterer shown. (Courtesy of James Schwenck.)

Bobwhite Quail

For bobwhite raising, Coleman (*132*) of the White Oak Quail Farm in Virginia recommends that 1 or 2 hours after the bobwhite chicks are placed in the brooder, they should be given dry quail mash ad libitum in small trays, clean coarse sand, fresh tender greens, and water. The water used for the first few days is drawn several hours before using and allowed to warm to room temperature, to prevent chilling the quail.

The greens (lettuce, alfalfa, or clover) should be fed at least three times daily from the first. They are cut fine with scissors and sprinkled on the water and in the sand tray until the birds are about 4 weeks old, when they are old enough to pick at larger greens.

On the fifth day from hatching, Coleman adds a little pulverized oystershell and baby-chick size charcoal in the sand tray, mixing them with the sand. Several days later he adds baby-chick size oystershell. Coleman does not feed any tomatoes, cucumbers, apples, or carrots, having found them of little value in the diet of either young or mature quail that receive a balanced diet supplemented with fresh greens.

At the fifth week, Coleman feeds a chick grain-seed mixture, sparingly, in the afternoon, so that the birds will be forced to eat considerably more mash than grain every day. When the birds are 10 weeks old they are started on a grain-seed mixture suitable for mature bobwhites. During the laying period (fig. 11, *C*), Coleman believes that—

> it is very important to control the amount of grain-seed mixture given so that the quail are forced to eat the mash freely. The egg-producing ingredients are contained in the mash and if the birds are given all the grain they want they will eat little, if any, mash, and the result will be poor egg production. In the winter, especially during the severe weather, it is well to feed more grain-seed mixture than mash, but at no other time is it advisable to do so. However, as already emphasized, keep the mash before the birds at all times, for all ages; from the very first feeding. Of course, they are fed in trays (never on the ground) which are cleaned often.

Consistency of Mash

Some breeders may inquire: Is it best to feed mash wet or dry, as fine or coarse meal, or as pellets?

The practice of feeding wet or moist mash is rapidly becoming obsolete. It requires extra time and labor and is messy, unsanitary, and unnecessary. Unless fresh batches only are kept before the birds and the receptacles are cleaned thoroughly every day, there is great danger of the birds eating sour, contaminated feed that will be very injurious.

Many breeders use a finely ground meal so that each mouthful of feed will theoretically contain all the ingredients of a balanced diet and the birds will not be able to pick out the more favored ingredients. Although undoubtedly these ends are achieved more or less by use of a powdery feed, certain disadvantages must be considered. Birds, both game and domestic, prefer discernible particles. Even with newly hatched game chicks, Handley (Stoddard (*1105*)) points out that feeds—

which contain some such ingredient as small flakes of wheat bran, are eaten by baby quail in greater quantity than are plain foods, apparently because of the presence of objects that readily catch the eye.

Powdery feed irritates the birds' nostrils, often caking there, and consequently may lead to nose picking and cannibalism by other birds.

Feed pellets have become popular because they eliminate the bad features of both powdery and coarsely ground feed. Feed manufacturers are putting both mash and pellets on the market. No study is known to have been made on these two types of feed for game birds, however. Work has been done with domestic fowls, but the results are not conclusive. One interesting study conducted by the workers at Pullman, Wash. (*194*), showed that domestic turkey poults from 2 to 10 days old found the pelleted feed more attractive and palatable than mash. However, no significant difference was noted at 28 weeks in the body weights of either the hens or toms fed mash, mash and pellets, or pellets supplemented with scratch grain and green feed. Likewise, the lots fed mash, mash and pellets, and pellets alone ate practically the same quantities of feed during the 28 weeks. The lots of turkeys fed on pellets and scratch grain brought slightly higher returns over feed costs than those fed by the other methods. The amount and cost of feed per pound of gain were both slightly less in the lots fed pellets and scratch grain.

"Cafeteria" Feeding

The value of "cafeteria" or free-choice feeding of pheasants was studied by Callenbach and Hiller of Pennsylvania State College (*185*). The results indicate that this method does not give satisfactory results as measured by growth, feather development, or livability. Also it is necessary to supply somewhat more feeding space per bird than for ordinary grain and mash feed.

PASTURE AND RANGE IN LIVESTOCK FEEDING

by P. V. Cardon, W. R. Chapline, T. E. Woodward, E. W. McComas, and C. R. Enlow[1]

THREE classes of feed available for livestock—pasture and range forage, harvested forage, and miscellaneous feeds—are discussed in the following three articles. This one deals with pasture and range, telling about kinds of pasture, grazing methods, pasture management, the relationship between pasture and other feeds, range forage, the maintenance of production on the range. and some of the research on soils and fertilizers as related to pastures.

PRIMITIVE MAN, dependent as he was on game for his food, must have recognized the "universal beneficence of grass." It is easy to imagine that he came to associate the differences in the forage upon which his quarry grazed with the differences in the quality of his meat.

With the domestication of cattle, sheep, and horses, the provision of suitable grazing for his animals became one of man's chief responsibilities. History is replete with tales of combat in which neighbors, tribes, and nations contended for grass for their flocks and herds. Recent range wars in our West are modern versions of man's age-long struggle for grass.

In the United States today that struggle has entered a different phase—in some respects a new phase. With no virgin grasslands beyond the horizon, the eyes of the grazier are turned back upon the grass within his own fence lines or upon controlled public ranges. His hope lies now in grass restoration and maintenance and in providing not only more but better grass—better in a nutritional sense. For even within the last decade developments in the field of nutrition have shown that the nutritive properties of green plants are not only beneficial but essential to health, growth, and reproduction in livestock.

The factors controlling the nutritional values of green forage are

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[1] P. V. Cardon is Assistant Chief, formerly Principal Agronomist in charge of the Division of Forage Crops and Diseases, Bureau of Plant Industry; W. R. Chapline is Principal Inspector of Grazing, in charge, Division of Range Research, Forest Service; T. E. Woodward is Senior Dairy Husbandman, Division of Dairy Cattle Breeding, Feeding, and Management, Bureau of Dairy Industry; E. W. McComas is Animal Husbandman, Bureau of Animal Industry; and C. R. Enlow is Principal Agronomist, in charge, Agronomy Division, Soil Conservation Service.

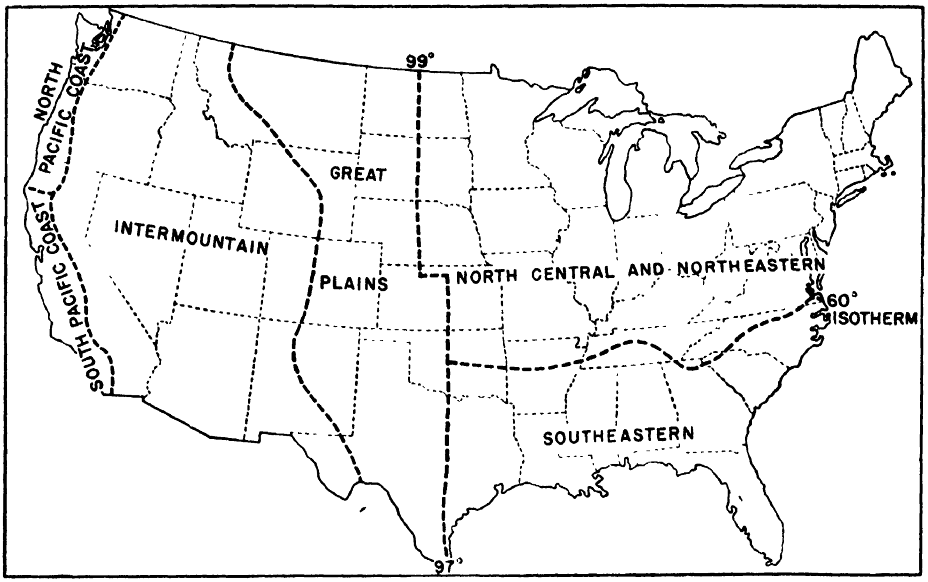

Figure 1.—Major grazing regions of the United States.

as complex as they are numerous, and present knowledge of them is admittedly limited, as will become plain in the following pages; but enough is known to point the way to better grass and its more effective use. As we move in that direction, new facts and greater knowledge will develop to guide further progress.

GRAZING REGIONS AND PRINCIPAL PLANT SPECIES

Approximately 60 percent of the total land area of the United States is grazed at least part of the year (*1167*). The type of grazing land, as well as its carrying capacity and seasonal use, varies according to topography, soil, and climate, all of which govern the number and kind of species constituting the forage. Regional differences with respect to those factors characterize large geographic areas such as the Great Plains. The approximate boundaries of the major grazing regions of the United States are shown in figure 1. This map is supplemented by table 1, which lists the more abundant pasture species in each region. Many more species are recognized as being of importance, but it is not practicable in this article to present a complete list.

WHY PASTURE AND RANGE ARE TREATED SEPARATELY

There is a distinction, though not a basic difference, between farm pastures and the range. Farm pastures as a rule are relatively limited grazing areas, usually privately owned, which are units of farm enterprises, especially in humid or irrigated regions. Ranges, on the other hand, are relatively large grazing areas, either privately or publicly owned or controlled, located on nonfarming land, mostly in the semiarid and forested parts of the United States.

Unharvested herbage includes all feed gathered directly by animals.

TABLE 1. - *Most abundant grasses and legumes comprising the forage in each of the generally recognized grazing regions of the United States as shown in figure 1*

North central and northeastern		Southern		Great Plains	
Grasses	Legumes	Grasses	Legumes	Grasses	Legumes
Kentucky bluegrass (*Poa pratensis*). Timothy (*Phleum pratense*). Redtop (*Agrostis alba*). Orchard (*Dactylis glomerata*). Canada bluegrass (*Poa compressa*). Tall oatgrass (*Arrhenatherum elatius*). Meadow fescue (*Festuca elatior*). Smooth brome (*Bromus inermis*). Sudan (*Sorghum vulgare* var. *sudanense*). Ryegrasses (*Lolium* spp.). Bents (*Agrostis* spp.). Reed canary (*Phalaris arundinacea*). Beardgrasses or bluestems (*Andropogon* spp)	White clover [1] (*Trifolium repens*). Korean lespedeza (*Lespedeza stipulacea*). Sweetclovers (*Melilotus* spp.). Alfalfa (*Medicago sativa*). Common lespedeza (*Lespedeza striata*). Red clover (*Trifolium pratense*). Alsike clover (*Trifolium hybridum*). Hop clover (*Trifolium procumbens*). Black medic (*Medicago lupulina*). Crimson clover (*Trifolium incarnatum*).	Bermuda (*Cynodon dactylon*). Carpet (*Axonopus compressus*). Johnson (*Sorghum halepense*). Dallis (*Paspalum dilatatum*). Vasey (*Paspalum urvillei*). Redtop (*Agrostis alba*). Bahia (*Paspalum notatum*). Rescue (*Bromus catharticus*). Rhodes (*Chloris gayana*).	Common lespedeza (*Lespedeza striata*). Hop clover (*Trifolium dubium*). White clover (*Trifolium repens*).[1] Persian clover (*Trifolium resupinatum*). Black medic (*Medicago lupulina*). Spotted bur-clover (*Medicago arabica*).	Gramas (*Bouteloua* spp.). Wheatgrasses (*Agropyron* spp.). Buffalo (*Buchloe dactyloides*). Bromes (*Bromus* spp.). Galletas, tobosa, and curly mesquite (*Hilaria* spp.). Beardgrasses or bluestems (*Andropogon* spp.). Sudan (*Sorghum vulgare* var. *sudanense*). Bluegrasses (*Poa* spp.). Timothy (*Phleum pratense*). Redtop (*Agrostis alba*). Rescue (*Bromus catharticus*). Rhodes (*Cholris gayana*).	Sweetclovers (*Melilotus* spp.). Alfalfa (*Medicago sativa*).

TABLE 1.—*Most abundant grasses and legumes comprising the forage in each of the gentrally recognized grazing regions of the United States as shown in figure 1—Continued*

Intermountain		North Pacific coast		South Pacific coast	
Grasses	Legumes	Grasses	Legumes	Grasses	Legumes
Wheatgrasses (*Agropyron* spp.). Gramas (*Bouteloua* spp.). Bromes (*Bromus* spp.). Galletas, tobosa, and curly mesquite (*Hilaria* spp.) Bluegrasses (*Poa* spp.). Timothy (*Phleum pratense*). Redtop (*Agrostis alba*). Bermuda (*Cynodon dactylon*). Beardgrasses or bluestems (*Andropogon* spp.)	Alfalfa (*Medicago sativa*). White clover (*Trifolium repens*).[1] Sweetclovers (*Melilotus* spp.). Alsike clover (*Trifolium hybridum*). Red clover (*Trifolium pratense*). Black medic (*Medicago lupulina*). California bur-clover (*Medicago hispida*). Strawberry clover (*Trifolium fragiferum*).	Ryegrasses (*Lolium* spp.). Kentucky bluegrass (*Poa pratense*). Bents (*Agrostis* spp.). Reed canary (*Phalaris arundinacea*) Orchard (*Dactylis glomerata*). Meadow fescue (*Festuca elatior*). Redtop (*Agrostis alba*) Timothy (*Phleum pratense*). Tall oatgrass (*Arrhenatherum elatius*) Meadow foxtail (*Alopecurus pratensis*)	Red clover (*Trifolium pratense*). White clover (*Trifolium repens*).[1] Hop clover (*Trifolium dubium*). Alsike clover (*Trifolium hybridum*).	Fescues (*Festuca* spp.). Bromes (*Bromus* spp.). Wild oats (*Avena* spp.). Bermuda (*Cynodon dactylon*). Sudan (*Sorghum vulgare* var. *sudanense*).	California bur-clover (*Medicago hispida*). Alfalfa (*Medicago sativa*). White clover (*Trifolium repens*).[1] Black medic (*Medicago lupulina*).

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[1] Includes Ladino clover.

The same physical and biological factors influence, though perhaps in varying degrees, the nutritional value of plants whether they are in farm pastures or on the range. Pasturage consists principally of mixtures of tame grasses and legumes. Range forage usually consists of a mixture of herbaceous species, mainly native grasses and legumes, but often includes an admixture of sedges, rushes, and other grasslike plants, of weeds—the forbs of the scientist—and sometimes of woody plants as well. The forage gathered from shrubs or trees is called browse. Nuts that have fallen from trees and are used as feed are called mast. Mast and browse are important chiefly on ranges. In some areas and in certain seasons weeds constitute an important part of pasturage. Occasionally the weed of today may be classed as an important forage plant tomorrow.

The major differences, then, between pastures and the range pertain to geographic distribution, size of units, kind of vegetation, and use. Pasture management usually aims at maintaining maximum production of young palatable growth, while this is not ordinarily possible on range lands, where drier conditions limit regrowth of plants after grazing. These differences are considered of sufficient importance to justify in this article a separate section on the range to meet the special interests of range users.

FARM PASTURES

ECONOMIC IMPORTANCE AND MAJOR USES

No accurate estimate can be made of the proportion of the total feed supply of the United States that is derived from pastures. Roughly, however, it would appear that pastures provide about one-third of the nutrients used by dairy cattle, while beef cattle and sheep probably obtain half of their feed from pastures and livestock on the range considerably more than half from range forage.

Semple and others (*1027*) [2] cite the results of cost studies made by the United States Department of Agriculture to show that pasturage furnished nearly one-third of the total sustenance of cows in market milk production while constituting only one-seventh of the total feed cost. They show also that on 478 Corn Belt farms producing beef calves—

> the breeding cows obtained practically their entire living from pasture for 200 days and from roughage and concentrates for 165 days. The pastures which were furnishing a little more than half of the total sustenance were credited with only one-third of the feed bill.

Misner (*794*) has shown that in New York the total cost of milk production on pasture was 9.7 cents per cow per day, with returns of 34 cents. The cost of winter feed, on the other hand, was 38 cents per cow per day, with the same returns as on pasture.[3]

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[2] Italic numbers in parentheses refer to Literature Cited, p. 1075.

[3] The practical importance of information as to the nutritive value of pasturage in terms of other feed crops and the relative cost of the nutrients derived from pasturage and from other crops is so great as to command the interest of various scientific groups in the United States and Canada, such as the American Society of Animal Production, the American Dairy Science Association, the American Society of Agronomy, and the Canadian Committee on Pasture and Hay Production. These four groups are considering joint effort designed to assemble and evaluate available data to serve as a guide to farmers in planning feed production. In the meantime certain European countries, especially the Scandinavian and Germanic countries, have assembled data of this type on the feed crops of those countries that are widely used there.[4]

[4] PIETERS, A. J. A DIGEST OF SOME WORLD PASTURE RESEARCH LITERATURE. U. S. Dept. Agr., Div. Forage Crops and Diseases, Bur. Plant Indus. 1937. [Mimeographed.]

The economy of pastures in livestock farming has been shown by similar results of cost studies in several other States. It should be remembered in this connection that even greater returns might be expected on improved pastures under good management, although adequate cost data on this point are not available. Various studies in Europe and some in this country indicate notable increases in forage yields and animal products on pastures following good management, including the use of improved pasture species, the proper use of fertilizers, or suitable grazing practices. These and other studies indicate also that through good management the pasture season may be extended and made to produce more satisfactory seasonlong returns.

Pastures may serve as the total source of feed or, more often, as the principal seasonal source for different classes of livestock. They can be depended on for the total feed requirement only in limited areas where yearlong or continuous grazing is possible. In most regions of the United States it is possible to graze only during limited periods, so that pasturage does not provide as much of the total annual feed requirements as hay, silage, and concentrates combined, although it usually provides the major portion of feed for the time it is used.

In the United States pastures are grazed chiefly by cattle, sheep, and horses, and also to some extent by hogs, especially alfalfa pastures. In some areas, the use of pastures by poultry is becoming more common. In this country there is less tendency to graze cattle and sheep on the same pasture than in some other countries—in Great Britain, for instance, mixed grazing is commonly practiced in the belief that the herbage is thus more completely utilized. In certain sections of the United States, however, mixed grazing is practiced regularly, as on the Edwards Plateau of Texas, where cattle, sheep, and goats use the same pastures.

KINDS OF PASTURES

Pastures may be classified (*926*, *1027*) as permanent, temporary, and supplemental, according to the length of time they are to be used; or on the basis of the plants that make up the pasturage, as tame and wild, although the latter are now commonly classified as range.

Permanent pastures in the United States are found most commonly on land that cannot be used profitably for the culture of field or horticultural crops. They occur on hill lands, in marshes, and in the woods and forests. The western ranges, also, may be regarded as permanent pastures. The common characteristic of permanent pastures is that they are seldom if ever broken by cultivation, except as their surfaces may be disturbed by renovation practices.

Temporary pastures are of diverse character, but include all crop fields used as pastures for a short period. Fallow land is sometimes pastured to utilize and control weed growth. Fields of seedling-grain crops, as oats, barley, and wheat, are often pastured in the fall or spring without damaging the stand or reducing the ultimate yield of grain. Stubblefields likewise are pastured, as are meadows after the hay crop is removed. Again, such crops as cowpeas, velvetbeans, soybeans, rape, and peanuts may serve as temporary pastures at some time during their growth periods.

Supplemental pastures include those which are seeded to some crop such as Sudan grass or lespedeza, for the purpose of providing pas-

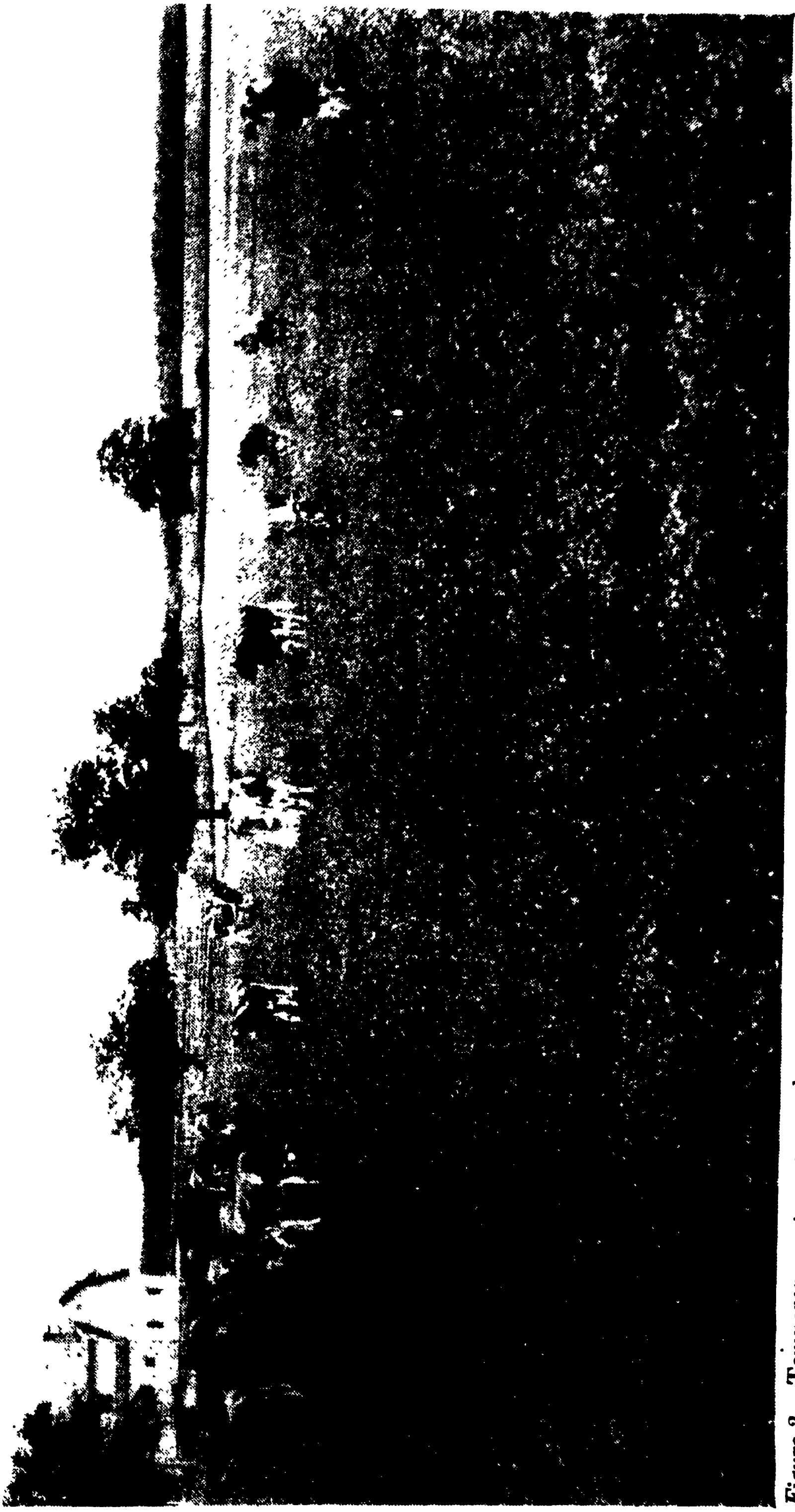

Figure 2.—Temporary pastures to supplement permanent pastures when the latter are relatively unproductive afford a means of maintaining milk flow at a high level throughout the season.

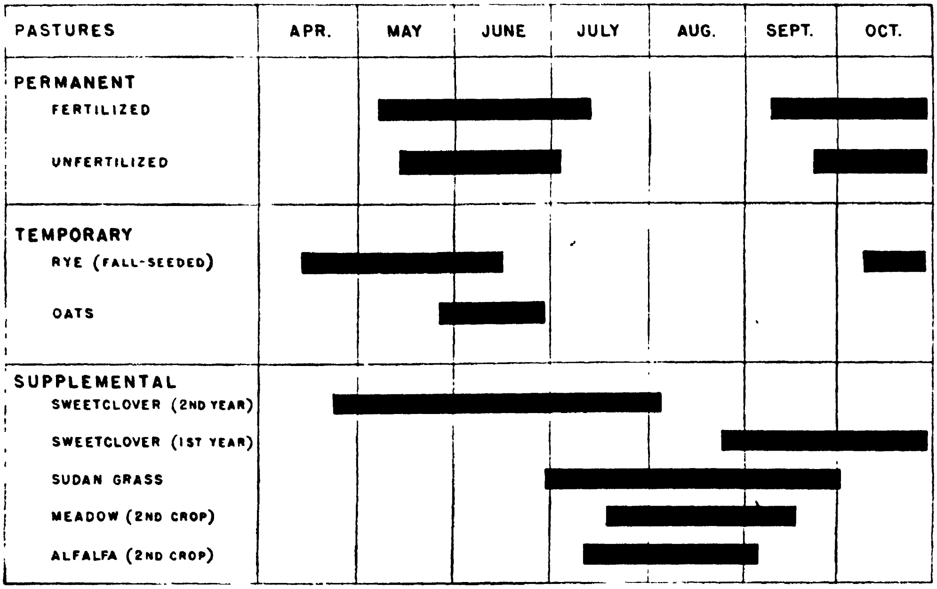

Figure 3.—Schematic representation of combined use of permanent, temporary, and supplemental pastures designed to provide adequate pasturage throughout the season. Originally planned for Iowa, this scheme could be used as a guide in other States, substituting temporary and supplemental pasture crops adapted to the locality. (Adapted from Iowa State College Extension Circular DH 46.) The rectangles black show the periods when the pastures are utilized.

turage to supplement permanent pastures during the season when the latter are relatively unproductive, a condition characteristic of Kentucky bluegrass pastures in midsummer (fig. 2).

Tame pastures may include any of the foregoing types when composed principally of domesticated grasses, as Kentucky bluegrass, redtop, timothy, orchard grass, and Bermuda grass, alone or in mixtures with white clover or other legumes.

By a combined use of permanent, temporary, and supplemental farm pastures, farmers are able ordinarily to provide adequate seasonlong pasturage (fig. 3). Such a plan is generally less feasible in range country, but to some extent the same end often is accomplished by moving the livestock from one range to another, as from spring-fall, to summer, and thence to winter range.

In pasture experiments conducted in Missouri (*337*) it was found that beef cattle on permanent bluegrass pasture made almost 60 percent of their total gains in weight during the first 60 days; about two-thirds of the total season's gains were made from the first one-third of the full pasture season. By supplementing permanent pasture with Korean lespedeza, the carrying capacity and nutritive value of the pasture herbage has been increased. The Korean lespedeza furnished grazing from late June until late September, when permanent bluegrass pastures are practically dormant.

GRAZING METHODS

Grazing may be seasonlong or, in some favorable areas, yearlong. Either seasonlong or yearlong grazing may be continuous, or it may be intermittent with no attempt at regularity. Again, a pasture or range may be divided into two parts which are grazed alternately; this is called alternate grazing. When a pasture or range is divided in such a way as to rotate the use of the various segments in regular order, grazing is referred to as rotation grazing. Deferred grazing—keeping the animals off the pasture until after the grasses, including the seed crop, are mature—is sometimes practiced to insure natural reseeding or to stimulate vegetative reproduction. In actual practice, especially on the range, deferred and rotational grazing are frequently combined.

In the practice of any of the foregoing methods, the pasture may be adversely affected by premature grazing, that is, grazing too early in the season, before the ground is firm or the grasses have made sufficient growth; or by overgrazing, which results in the loss of vigor of desirable vegetation and creates a condition favorable to replacement of such vegetation by weeds and other less desirable plants. The herbage available determines the carrying or grazing capacity of an area, that is, the ratio of animals to the unit of area that will furnish ample sustenance, as one cow to 2 acres, three sheep to 1 acre, one steer to 20 acres, and so on.

Overgrazing, or grazing beyond carrying capacity, ordinarily is inadvisable. The serious consequences of overgrazing have been emphasized, during recent years, in many publications pertaining to soil conservation, erosion control, and range improvement. It has received less emphasis in literature pertaining to farm-pasture management, although overgrazing is as much to be avoided on farm pastures as upon the range. It weakens desirable species, thereby making way for less desirable species, including weeds.

Grazing short of carrying capacity may also be inadvisable under some conditions, especially where the grass tends to "get away," and become with maturity relatively less palatable, digestible, and nutritious. If, under such conditions, the grass could be clipped and ensiled, as is commonly done in some countries and to an increasing extent in this country, much good feed might be saved and the pasture left uninjured.

In an experiment on methods and rates of grazing at Beltsville, Md. (*502*), it was found that the crude protein in the herbage under continuous light grazing averaged 13.04 percent as compared with 14.56 under continuous heavy grazing and 13.40 under alternate heavy grazing. The calcium and phosphorus contents were 0.59 and 0.30 percent, respectively, under continuous light grazing, 0.75 and 0.32 under continuous heavy grazing, and 0.60 and 0.34 under alternate heavy grazing.

The Washington Agricultural Experiment Station (*520*) reports that rotation grazing did not improve the quality of herbage as measured by chemical composition when compared with the herbage obtained from continuous grazing, but it did increase the yield.

It would appear from these experiments that the relative advantages in rotation and continuous grazing are dependent upon differences in local soil, climate, and management factors.

A 6-year experiment conducted at Beltsville, Md. (*1270*), in which permanent pastures were grazed by dairy cattle in a six-field rotation

Figure 4.—Good pasturage provides a perfect ration for cows producing a medium or small quantity of milk, but even good pasturage may require supplements for high-producing cows.

and continuously, showed a 10.4-percent greater yield under rotation grazing.

NUTRITIVE VALUES OF PASTURAGE

Besides providing cheap succulent feed, pasturage is of great importance as a source of proteins, minerals, and vitamins (*1027*). The immature plants are much richer in protein than the same plants at a later stage of growth. The young plants are also softer and more tender, and the dry matter, being less fibrous, is more easily digestible. Most if not all of the minerals of importance in animal nutrition may occur in pasture herbage, although, as will be shown, this depends in large measure on differences in the soil environment and the inherent ability of species of plants to extract nutrients from the soil.

Influence of Physical Factors

Rainfall is probably the greatest single factor influencing the yield and nutritive value of grasses. Most species are more palatable, digestible, and nutritious under favorable moisture conditions than when the moisture supply is inadequate. Many of the grasses of the dry Great Plains region, however, have in their physiological make-up the ability to retain their palatability and nutritive value at mature stages of growth when their moisture content is low.

In addition to moisture, temperature plays an important part in influencing the nutritive value of many perennial pasture grasses. As the temperature increases during the summer months, production decreases and the ratio of stem to leaf increases, with an increase in crude fiber and a decrease in crude protein. High temperature reduces the quality of adapted varieties of pasture herbage to the greatest extent in the north humid regions. Grasses grown in the South are adapted to and withstand high temperatures. Bermuda grass, Dallis grass, Bahia grass, molasses grass, and other southern species all require high temperatures for their most rapid growth, but at the same time they must have ample moisture and fertile soil. Buffalo grass, crested wheatgrass, and grama grass, all adapted to regions of limited rainfall such as the Great Plains, make ample growth with limited moisture and at reasonably high temperatures.

Influence of Management Practices

Among the various factors influencing the nutritional value of herbage, the management factor is of primary interest to the grazier, because it is one that he can control. Through intelligent management he is able to derive from his pastures the maximum returns possible under the environmental conditions governing his operations.

Pasture management involves among other things (1) choice of species, (2) use of fertilizers, and (3) grazing practices employed.

Choice of Species

Species are chosen to provide a desired mixture of grasses and legumes. Because of differences in habits of growth and seasonal response to environmental influences, several grasses are more likely to insure grazing over a longer season than will any single grass. Through the proper selection of grass species it may be possible to have one or more of them growing throughout the grazing season. Legumes in the mixture are important in that they increase the yield of the herbage and in the more mature stage add to its nutritive value by increasing the protein content. Because of their ability to supply to the soil nitrogen extracted from the air through their root nodules, legumes also stimulate the growth of the associated grasses and increase their protein content.

Johnstone-Wallace (*590*) reports that the protein content of Kentucky bluegrass grown alone averaged 18 percent while that of the same grass grown in association with white clover averaged 25 percent—an increase of more than one-third. Timothy grown alone averaged 24 percent, but with white clover 30; orchard grass averaged 23.5 percent alone, but 29.3 with clover.

Choice of species is also important with respect to palatability—a term commonly used but little understood. Graziers know that domestic animals display marked preference for certain pasture plants, whereas they avoid others except when forced by hunger to eat them. Moreover, they prefer a given species when at a particular stage of growth, as shown by Stapledon (*1099*) and by Forsling and Storm on a Utah range (*378*). The same discrimination has been observed among rodents and insects. Whether or not animals smell or taste a difference in pasture plants and to what that difference may be ascribed are points that remain to be determined. Yet palatability cannot be ignored in pasture management. Whatever it is, it influences the grazing value of any pasture. It is important, therefore, to choose species that are palatable and to graze them when they are most palatable, that is, in early immaturity. Bromegrass, Kentucky bluegrass, and timothy are generally regarded as highly palatable, whereas such grasses as redtop, bentgrass, and many natives species are relatively low in palatability, at least in certain stages of growth. Less palatable grasses may often be used advantageously, however, if their growth habits are such as to provide herbage in seasons when more palatable species are dormant. The relationship between palatability and nutritive value is not clear, but it is generally conceded that palatable species are more nutritious than unpalatable species, possibly because of the greater quantity consumed or some related qualitative factor.

Use of Fertilizers

Because different species of pasture plants respond differently to various nutrients in the soil and because their use of nutrients influences their composition, it is plain that the application of fertilizers should be governed by plant requirements as well as by soil analysis. In other words, although soil analysis may reveal certain deficiencies which may be corrected through the use of fertilizers, experiments indicate that these fertilizers should be applied with a view to satisfying the requirements of the different grasses and legumes in the pasture mixture if the greatest benefits from fertilizer use are to be realized.

This, however, would require knowledge not yet sufficiently developed to warrant definite recommendations. Lacking specific knowledge on this subject, the farmer can proceed only in the light of more

Figure 5.—Beef cattle gains are made at less expense on high-quality pasture than by dry-lot feeding.

general information. It is known, for instance, that grasses usually respond better than legumes to nitrogen, whereas legumes are more responsive than grasses to phosphorus and potash. Nitrogen not only stimulates grass but increases its protein content. The stimulus to legume growth afforded by applications of lime, phosphorus, and potash, where deficient, also increases the protein content of the herbage. Overstimulation of legumes, on the other hand, may be detrimental to the associated grasses. In applying nitrogen it is important also to avoid excessive stimulation of grass growth, since this may prove injurious to legumes growing in the mixture. The objective should be to keep both grasses and legumes in the herbage. It is advisable in this connection to consult the county agricultural agent, who usually has access to information from the State agricultural experiment station or the United States Department of Agriculture relative to the various soil types in the county and their fertilizer requirements. If such information is not available the county agent may be able to make arrangements for obtaining it.

Robinson and Pierre (*975*) emphasize the importance of considering the costs of pasture fertilization and liming as a long-time investment:

> Although the initial cost of improving a depleted pasture may range from $5 to $10 an acre, it should be remembered that once a good sod is reestablished, the cost of maintaining such a sod will be relatively low.

This statement is supported by data showing the residual effects of lime and superphosphate treatments on yield and composition of the herbage.

A more technical discussion of the results of research on the effects of soil and fertilizers on pasture herbage will be found at the end of this article.

Grazing Practices

Grazing practices also influence the botanical composition of pastures and hence the nutritive value of the herbage. Since pasture species differ in palatability, some are more readily grazed than others, which tends to jeopardize the more palatable and to protect the less palatable species. Likewise, some species are naturally more persistent than others, so that even though equally palatable the more persistent tend to survive while the less persistent tend to disappear under grazing. Again, species differ in their ability to recover after grazing, some requiring more time than others. The time and intensity of grazing with respect to the stage of growth also affects persistency, especially that of species dependent upon natural reseeding for reproduction. If these are grazed in a manner to prevent seed formation they do not survive.

McCarty's studies with mountain brome (*713*) show that early spring growth is made at the expense of carbohydrates stored in the roots and stem bases during the previous autumn, but that subsequent normal growth and yield are independent of stored carbohydrates, being the products of current carbohydrate manufacture by the plant. Excessive early grazing, therefore, tends to deplete stored reserves of carbohydrates and to reduce the vigor of the plants. These findings further indicate the advisability of moderate grazing designed to leave enough herbage after each grazing period "to permit sufficient manufacture and storage of carbohydrates to maintain the life and proper vigor of the plants."

Time of grazing with respect to the stage of maturity of the herbage is of the utmost importance. Young, succulent herbage is richer in protein than mature plants of the same species, contains more calcium and phosphorus, and is higher in vitamins, and the dry matter is more digestible.

In South Carolina (*322*) it was found that, as indicated by chemical composition, rapidly growing plants produce greater yields and have superior feeding value; also that the feeding value of pasture herbage is lower during the latter part of the growing season because of changes in chemical composition.

Mortimer and Ahlgren (*822*) report that Kentucky bluegrass cut to 8 to 10 inches high was lower in phosphorus and calcium than the same grass cut to 4 to 5 inches.

In studies conducted in North Dakota (*541*) with many grasses both introduced and native, it was found that in general protein and ash (mineral content) decreased and carbohydrates increased as plants approached maturity.

Use of Hay and Concentrates to Supplement Pasturage

Dairy Cattle

Studies made of seasonal milk production in 12 States show that the most favorable time for the production of milk is in the spring when the pasture grass is at its best. They show also that after the flush of the pasture season, which lasts for only a month or so, the production declines rapidly. The first growth in the spring is tender, palatable, and abundant. Cows will eat as much as 150 pounds a day. If no deduction is made for the energy used in grazing, this amount is enough to support a production of 40 pounds of milk with an average percentage of butterfat. The grass soon becomes either tougher, less palatable, and more fibrous, or it becomes more scarce. The result is that cows do not eat as much as they did earlier in the season. This fact is advanced as the principal explanation of the rapid decline in production during the summer.

Aside from common salt, which is needed with all rations, young pasturage grown on a fertile soil provides a perfect ration for cows producing a medium or small quantity of milk (fig. 4). The content of protein, vitamins, and minerals is ample both in kind and quantity. Some dairy cows, however, have been developed to a state of productivity where they cannot obtain enough of the energy-producing constituents from pasturage alone to maintain their weight and at the same time produce the quantities of milk of which they are capable. Such cows should have supplementary feed. In the spring when the grass is eaten in large quantities and the cows maintain a good fill of forage, the supplementary feed should be concentrates and should be given to all cows producing more than, say, 25 or 30 pounds of average-testing milk.

As the pasturage becomes shorter or tougher following the early flush growth, the decrease in forage consumed in the form of pasturage should be made up with hay or silage or both. Even if cows are

Figure 6.—Good temporary pastures to supplement permanent pastures in midseason will carry sheep satisfactorily without the use of concentrates.

allowed all the hay and silage they will eat in addition to pasturage, the intake of nutrients will hardly equal the intake when they have access to flush pasturage. This means that while concentrates may be required for only that production over and above 25 or 30 pounds in the early part of the pasture season, they will be required for all production over and above a smaller quantity later in the season, even if the pasturage is supplemented with hay or silage, or both.

The intake of protein is usually less in the summer and fall than in the spring, because the herbage is either more mature or less abundant. In the spring any of the farm-grown cereal grains will be satisfactory to use as supplements because the need is for energy-producing feeds. Later in the season the protein content of the concentrate feed must be increased unless the protein needs are met by the generous feeding of legume hay.

Vitamins A and D are the only ones in the cow's ration the deficiencies of which have been shown to be serious enough at times to affect health. All fresh green pasture herbage has a high content of carotene from which vitamin A is formed in the animal body. No other common feed is equal to pasture herbage in content of carotene, and no other will increase the carotene content—as indicated by yellow color—or the vitamin A content of the butterfat to as great an extent as pasture herbage. Fresh, green pasture herbage is devoid of vitamin D, but this vitamin is synthesized within the body when the animal is exposed to direct sunlight. Because grazing cattle are usually in the sun, vitamin D need not be considered in estimating the adequacy of rations being fed to cows on pasture.

Pasturage is valuable for young dairy stock of all ages, but until the calves are about 1 year of age it should not constitute the sole ration, else the development of the calves will be arrested. The younger the calf the greater the need of supplementary feed. Probably for about the first 3 months of their lives calves should be fed about the same kind and quantity of feed whether or not pasturage is available. After this age the calf eats progressively larger quantities of grass and the proportion of supplementary feed can be correspondingly reduced until the calf is about 1 year old, when the supplementary feed may be discontinued. However, if quick maturity is desired a large-sized supplementary feeding should be continued. The supplementary feed of calves under 1 year on pasture should be both hay and grain, but of those over 1 year it need be only grain. If for any reason the pasturage becomes short or otherwise inadequate to keep the calves in a thrifty growing condition the supplementary feed should, of course, be increased.

Beef Cattle

It is generally agreed that beef cattle make gains at less expense on high-quality pasture than by lot feeding, yet much more time is usually required to get cattle fat enough for market by the use of pasture only (fig. 5). The success of a combination of pasturage with one or more concentrates has been demonstrated in the Corn Belt by Black and Trowbridge (*117*, *118*) in fattening calves prior to weaning. That this practice, involving what is known as creep feeding—the use of a feeding device in the field—is good economy in parts of the Appalachian region is indicated by McComas and Wilson (*726*).

Black and Wilson (*121*) found that it is possible to speed up the rate of finishing 3-year-old steers by feeding a mixture of corn and cottonseed meal while on good bluegrass pasture. Feeding a supplement increased the steer gains 37 percent over gains from pasture alone. Subsequent work at the same station has shown that it is possible to put a marketable finish on 2-year-old steers by supplementing their pasturage with a mixture of protein and carbohydrate concentrates. Moreover, steers fed a grain supplement during the last 84 of their 140 days on pasture were more profitable than those fed a supplement the entire time.

In order to get yearlings ready for slaughter in midsummer by feeding them a grain supplement on pasture, it is usually necessary to winter them on a ration somewhat higher than that on which older steers are wintered and considerably higher than that yearlings ordinarily receive.

Hogs, Sheep, and Horses

In swine production it frequently is advisable to supplement pasture with certain concentrates, although pasture is an important source of vitamin A and furnishes considerable protein and varying amounts of other nutrients. For example, if the pasture is composed largely of legumes, less calcium supplement will be needed. Robinson (*977*) and others have determined that swine are not only likely to be more thrifty, but also may be fattened more rapidly and more economically by feeding them supplements of carbohydrate and protein concentrates and a mineral mixture containing calcium and phosphorus on pasture, than when they are fattened in a dry lot.

For fattening lambs, average-quality pasture will give better results when supplemented. Harper (*475*) at the Indiana Agricultural Experiment Station reported that it did not pay to supplement good temporary pasture used in fattening lambs (fig. 6), but that permanent pasture alone gave less favorable results. It appears from subsequent research by Harper (*476*) that using good-quality temporary pasture as a supplement to permanent pasture in midsummer is probably a more profitable practice than feeding a supplement of concentrates to lambs on permanent pasture.

Permanent pastures and most kinds of temporary pasture when not overgrazed are important factors in keeping horses healthy and maintenance costs at a minimum. Such pastures do not, as a rule, need to be supplemented with hay or grain in order to nourish idle mares and young stock adequately. In the Corn Belt, work horses are pastured about 6 months of each year, but much of this time they are turned out only at night and on Sundays and holidays or during other short periods of idleness. Under these practices, pasture may be considered a supplement to the work-horse ration (fig. 7). In the Cotton Belt, pasture is used to a relatively small extent for work stock. In the Mississippi Delta, for example, it is reported that a mule is pastured an average of only about 34 days a year.

Use of Pasturage to Supplement Hay and Concentrates

Pasturage is not extensively used as a supplement to other feed. Usually when animals are on pasture the feed obtained there consti-

Figure 7.—For idle mares and young stock, good pastures usually are adequate, but for work horses the pastures should be supplemented by concentrates.

tutes the larger share of the total ration and for that reason the other feeds are considered supplementary rather than the pasturage.

In those sections of the country where the winter weather is not too severe, some of the clovers, grasses, and cereal grains may be seeded in the fall for winter pasturage. The amount of grazing provided by such crops is often limited and the continuity of grazing is often interrupted by inclement weather or soft ground. Winter pasturage cannot be depended on to provide any certain amount of grazing every year, although sometimes after crop failures pastures of winter cereals have been used to especially good advantage.

A few dairymen make a practice of feeding their herds on harvested forage and grain the entire year with very little pasturage. The pastures in such cases are regarded as convenient places to put their dry cows and young stock in order to lessen the labor of caring for the stock, although the pasturage, because of its content of vitamins, minerals, and protein, makes an especially good feed for both the young stock and the dry cows. The milking cows, too, are benefited by even small quantities of pasturage, particularly if the roughage fed in the barn is of poor quality.

THE RANGE

EXTENT AND SIGNIFICANCE OF THE WESTERN RANGE

The western range, pivotal in the economic and social structure of the far West, is a vast area covering 728,000,000 acres of forested and nonforested land mostly west of the one hundredth meridian (fig. 8).. Because of its meager precipitation, rough topography, and other adverse conditions, most of the range is suitable only for grazing. The importance of this area in animal nutrition is enormous—it furnishes cheap feed, costing one-fifth to one-tenth as much as hay or supplements, to approximately 11,000,000 cattle and horses and 27,000,000 sheep and goats for the equivalent of yearlong grazing. The range territory produces 75 percent of the Nation's output of wool and mohair, 55 percent in pounds of live weight of the sheep and lambs, and nearly 33 percent of the cattle and calves (*1158*).

This vast area is not under single ownership but includes private as well as Federal, State, and county lands. In fact, certain areas show a bewildering complex of ownership, which greatly complicates the problem of use and management. A considerable acreage of public land is grazed part of the year by farmers and ranchers whose personally owned lands do not supply a sufficient amount of forage for the livestock they possess. It is extremely important that the range be maintained in such manner as to assure a continuous supply of forage. If it is improperly used, the direct result is not only unstable livestock production, but far-reaching adverse effects upon watersheds, irrigation, wildlife, recreation, and other resource values.

Range livestock production is today definitely a part of western agriculture in which range use is integrated with crop farming. It is estimated that 35 percent of the feed consumed by western range livestock is supplemental feed raised on croplands or irrigated pastures.

In parts of the South also, forest ranges are an indispensable part of the agricultural set-up.

MAJOR USES OF THE RANGE

Cattle and sheep and, to a less extent, goats and horses are the principal kinds of livestock grazed on the western range. Elk, deer, and other wild species are dependent upon range forage and occasionally are overabundant on the range. Although cattle and sheep may be grazed on the same range unit, cattle prefer range predominantly grass, on not too steep a slope, and where there is daily access to water. Sheep feed on mixed grasses, weeds, and browse and are able to graze fairly steep and high ranges with infrequent watering places. Goats do well on good range lands, but are able to use forage on rough, brushy areas. Forage requirements of elk and deer are much the same as those of cattle and sheep, with preference for weeds and browse. An abundance of succulent forage in the spring is particularly important to give lambs, kids, and calves a proper start.

Many western range lands are used seasonally in order to obtain maximum value from the forage. Where the winter climate is mild and the grasses cure well on the stalk, thus providing nutritious dry forage, the range may be grazed yearlong, as in parts of the Great Plains. Other areas where grasses cure well, or where there is palatable browse, are used only in winter. Many foothill and high plateau ranges where growth starts rather early are used for spring grazing. Often livestock are brought back onto these spring ranges in the fall. The tender, green, luscious growth on the cooler, moister, higher mountain ranges is in great demand for summer grazing. On these, lambs and steers fatten readily. Herds are frequently driven long distances between summer and winter ranges—often 50 to 150 miles, and in extreme cases as far as 300 miles.

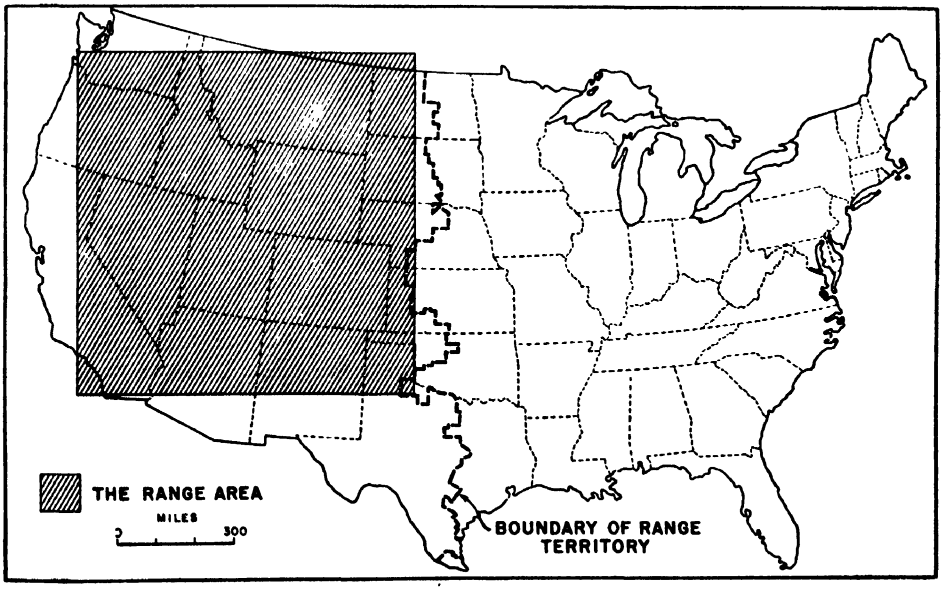

Figure 8.—The western range occupies roughly three-fourths of the land area west of the irregular line extending the length of the Great Plains.

FORAGE PRODUCED ON THE RANGE

Range Types and Species

As forage for grazing animals, the range offers only the natural wild vegetation. Some reseeding has been attempted, but on an acreage insignificant in comparison with the range as a whole. Owing to major differences in the soil, temperature, and rainfall, the vegetation naturally falls into 10 readily recognizable types, listed in table 2. Some of the more important forage species that characterize each are also given. The most extensive area (198,092,000 acres) is occupied by the short-grass plains, which rather abruptly succeed the tall-grass prairies, toward the west, in direct response to decreased total annual rainfall. To be sure, minor variations in soil and topography within any given type cause important local modification of the plant cover—for example, the growth of trees along a stream in an otherwise grassland area.

TABLE 2.—*Range types and grazing capacity* [1]

Range type	Some dominant species	Extent	Average per cow (5 sheep) per month
		Acres	*Acres*
Tall grass	Slender wheatgrass (*Agropyron pauciflorum*) Beardgrasses, or bluestem (*Andropogon* spp.). Porcupine grass (*Stipa spartea*).	18, 513, 000	2. 4
Short grass	Bluestem wheatgrass (*Agropyron smithii*) Blue grama (*Bouteloua gracilis*). Buffalo grass (*Buchloe dactyloides*). Curly mesquite (*Hilaria belangeri*).	198, 092, 000	4. 1
Pacific bunch grass	Bluebunch wheatgrass (*Agropyron spicatum*) Sandberg bluegrass (*Poa secunda*). California needlegrass (*Stipa pulchra*). Giant wild-rye (*Elymus condensatus*).	42, 534, 000	4. 5
Semidesert grass	Gramas (*Bouteloua* spp.) Mesquite (*Prosopis* spp.). Sacaton (*Sporobolus wrightii*).	89, 274, 000	6. 4
Sagebrush-grass	Bluebunch wheatgrass (*Agropyron spicatum*) Sagebrush (*Artemisia* spp.). Indian ricegrass (*Oryzopsis hymenoides*). Needlegrasses (*Stipa* spp.).	96, 528, 000	8. 9
Southern desert shrub	Saltbush (*Atriplex* spp.) Yucca (*Yucca* spp.). Various cacti.	26, 896, 000	11. 5
Salt-desert shrub	Black sagebrush (*Artemisia nova*) Shadscale (*Artriplex confertifolia*). Winterfat (*Eurotia lanata*).	40, 858, 000	17. 8
Piñon-juniper	Gramas (*Bouteloua* spp.) Junipers (*Juniperus* spp.). Muhly grasses (*Muhlenbergia* spp.). Piñion (*Pinus edulis*).	75, 728, 000	8. 4
Woodland chaparral	Chamise (*Adenostoma fasciculatum*) California oatgrass (*Danthonia californica*). Alfileria (*Erodium cicutarium*). Oaks (*Quercus* spp.).	13, 406, 000	9. 8
Open forests	Largely ponderosa pine (*Pinus ponderosa*) timber Fescues (*Festuca* spp.). Bromes (*Bromus* spp.).	126, 367, 000	5. 9
Total		728, 196, 000	

A balance in the range vegetation of the various climatic units would exist more or less indefinitely, notwithstanding occasional temporary upsets due to drought years, so long as no outside interference occurred. But, man and his grazing animals have disturbed the normal balance. With few exceptions, the principal perennial grasses once dominant and plentiful on the range were those most palatable to livestock, but these have often given way to less palatable plants.

In general, out of a total of at least 10,000 species growing on the range, probably only about 1,000 are of major or secondary importance (*695*). Each range type is a complex of species, but only a comparatively small number furnish the bulk of the forage. Generally speaking, perennial species, especially grasses, are the backbone of the range. With the exception of certain legumes, California oatgrass, some bromes, and fingergrasses, range annuals are, on the whole, of inferior palatability and forage value. Furthermore, annuals are subject to wide fluctuation in forage production.

Nutritive Values of Range Plants

Many palatable range plants, such as some of the wheatgrasses, saltbushes, and native clovers, compare favorably with alfalfa and other cultivated feeds in their chemical composition, as indicative of nutritive value; indeed, some have an even higher ratio of minerals or protein. Chemical values of plants are, however, not constant; there is a higher protein and phosphorus content in the early stages of growth, which gradually decreases as the plants approach maturity (*1098*). The chemical content of individual plants of the same species also varies with soil, exposure, altitude, and other ecological factors. In general, range plants of higher altitudes, whether grasses or weeds, are higher in crude protein and lower in fiber than plants of lower altitudes (*972*).

The composition of forage plants as it affects their actual nutritive value to the animals themselves, that is, the relation to animal metabolism, is of great significance. Research along this line on range forage plants is of rather recent development and much work remains for the future. Greaves (*433*), working with 16 species of range plants in Utah, found that a total phosphorus determination is a good indication of the nutritive value of the plant, because sulfur, protein, and crude fat all vary directly with phosphorus.

The Arizona Experiment Station has shown that blue grama is an extremely potent source of vitamin A, especially in the early stages of growth (*1081*). It has been found in California that vitamin A deficiency in the range-forage diet contributes to reproductive failure of cattle (*496*). The California Agricultural Experiment Station is continuing its investigations of vitamin A and mineral deficiences at the San Joaquin Experimental Range in cooperation with the California Forest and Range Experiment Station. Unpublished results of these studies show that with the drying of the annual type of plants on the range during the summer period nutritional values fell well below the minimum level for normal nutrition about the first of July, with both vitamin A and protein deficiencies. The phosphorus content of the plants was found to decrease with the protein, but the blood phosphorus of the animals remained normal. There was a severe loss in weight of animals and supplements were required to keep them gaining. Similar nutritional studies are now being made in a number of States.

MAINTAINING RANGE FORAGE AND LIVESTOCK PRODUCTION

Sustained livestock production on range lands depends on maintaining productivity of the range forage. Maintenance alone is not sufficient, however, since past drought and overuse have seriously depleted the grazing value and curtailed possible production. At the same time, the thinner stand of perennial grasses on the depleted range has exposed the land to increased erosion, which if left unchecked would further decrease productive values. It is of prime importance, therefore, if the productivity of the range is to be maintained and a continuous and ample forage supply for livestock assured, to graze the range in accordance with the life history and growth requirements of the most important palatable species. It is also important to be able to evaluate conditions at all times in order to adjust grazing to the capacity of the range (*1120*).

The perennial range grasses and other plants that furnish the forage for the livestock grazing on the range, manufacture in their green leaves the food they utilize in their growth. The start of growth in perennial grasses in the spring, as exemplified by mountain brome, depends primarily on carbohydrates manufactured and stored in their roots the previous autumn, while further production of herbage and of flowers and fruit depends on the manufacture of sufficient carbohydrates currently through the season (*713*). It will readily be seen, therefore, why it is essential to have a reasonable growth of grass in the spring before grazing begins and why too close utilization of the herbage at any time is detrimental to sustained forage production. Close use of the range at the same spring period each year is especially detrimental (*238*). However, grazing closely twice or even three times in a summer season, provided the first grazing is late enough and the intervals are sufficient for the vegetation to recover from each cropping, ordinarily does not seriously affect the yield and vigor of the plant cover (*1008*).

Forage production on the range must be accomplished under moisture conditions far more adverse than in humid pastures. Average precipitation in the range area is one-third that of the Middle West and East, and in 1 to 4 years out of every 10 there is less than 75 percent of this normally low average rainfall. However, range plants utilize their limited supply of available water with remarkable efficiency. Some native grasses require less than 400 pounds of water to produce 1 pound of dry material, in contrast with alfalfa which, in the same section, requires over 800 pounds (*1030*). Furthermore, it has been shown that soils from a Utah mountain range seriously depleted by erosion require approximately twice as much water to produce a given unit of dry plant weight of peas and wheat as do comparable soils not so depleted (*1004*, *1005*). During severe droughts, as in 1934, range grasses such as the gramas of Montana and New Mexico either fail to grow appreciably or dry up early in the season. Growth in height is greatly restricted in practically all species during drought years. Severe losses in density also follow droughts, as in southern New Mexico where black grama, even under protection from grazing, dropped in 1919 to 41 percent and in 1923 to 11 percent of its 1915 stand, following the droughts of 1916 to 1918 and 1921 to 1922 respectively (*841*). Overgrazing resulted in even lower stands of black grama during drought and in some cases killed it out entirely.

Because of the rather wide fluctuation in forage production from one year to another, ranges should normally be stocked on a conservative basis of 20 percent below their forage production in average years. Such conservative stocking not only provides a reserve of forage in case of drought, but also affords added soil protection and enables more rapid recovery of vegetation following drought or on otherwise depleted ranges (fig. 9). Also to insure most satisfactory use of forage by livestock without detriment to forage production, the range should be managed with full recognition of the suitability of various range types for the different classes of livestock, the best season for grazing, and suitable distribution of the animals over the area to avoid concentration (*198*, *584*). Deferred and rotation grazing allows deteriorated range to recuperate and often produces greater grazing values on range in good condition.

Many examples might be given of the value of desirable range-management practices in better livestock production. At the United States Range Livestock Experiment Station near Miles City, Mont., in studies handled cooperatively by the Forest Service, the Bureau of Animal Industry, and the Montana State Agricultural Experiment Station, 5-year-old cows grazing conservatively weigh from 40 to 90 pounds more than on range slightly overgrazed; an 84-percent calf crop was produced on the conservatively grazed range as compared to 70 percent on the overgrazed; the calves from the former range were heavier at birth, and one-third more pounds of calf at weaning time was produced per cow on the conservatively grazed range (*564*). On the Jornada Experimental Range in southern New Mexico grazing capacity is twice as great, calf crops are half again larger, and losses are one-fifth as great under conservative management as on comparable nearby unmanaged ranges. It is the overcoming of heavy losses during drought and extremely low calf crops which follow that accounts for the major differences (*377*). Livestock in a poor and emaciated condition are more subject to losses from malnutrition, disease, predatory animals, straying, and poisonous plants. Ordinarily animals do not eat a sufficient amount of poisonous plants to be of serious consequence unless they fail to obtain from their forage an adequate supply of the nutrients essential for their needs.

In parts of the West where breeding cattle are wintered on the range, supplemental feeding is particularly desirable. Experiments in Montana (*113*) showed that approximately 1 pound of cottonseed cake a head fed daily for 73 days during the winter as a supplement to the range enabled the cows to come through the winter in better condition than cows on range without a supplement, and they consistently produced calves heavier at birth and at weaning time. Lantow (*663*) found that feeding cottonseed cake at the rate of 1 pound a head daily to breeding cows on range in New Mexico was a highly desirable practice and usually more economical than feeding a supplement of corn. The relative price of corn and cottonseed cake would, of course, have to be considered in ranch practice. At the

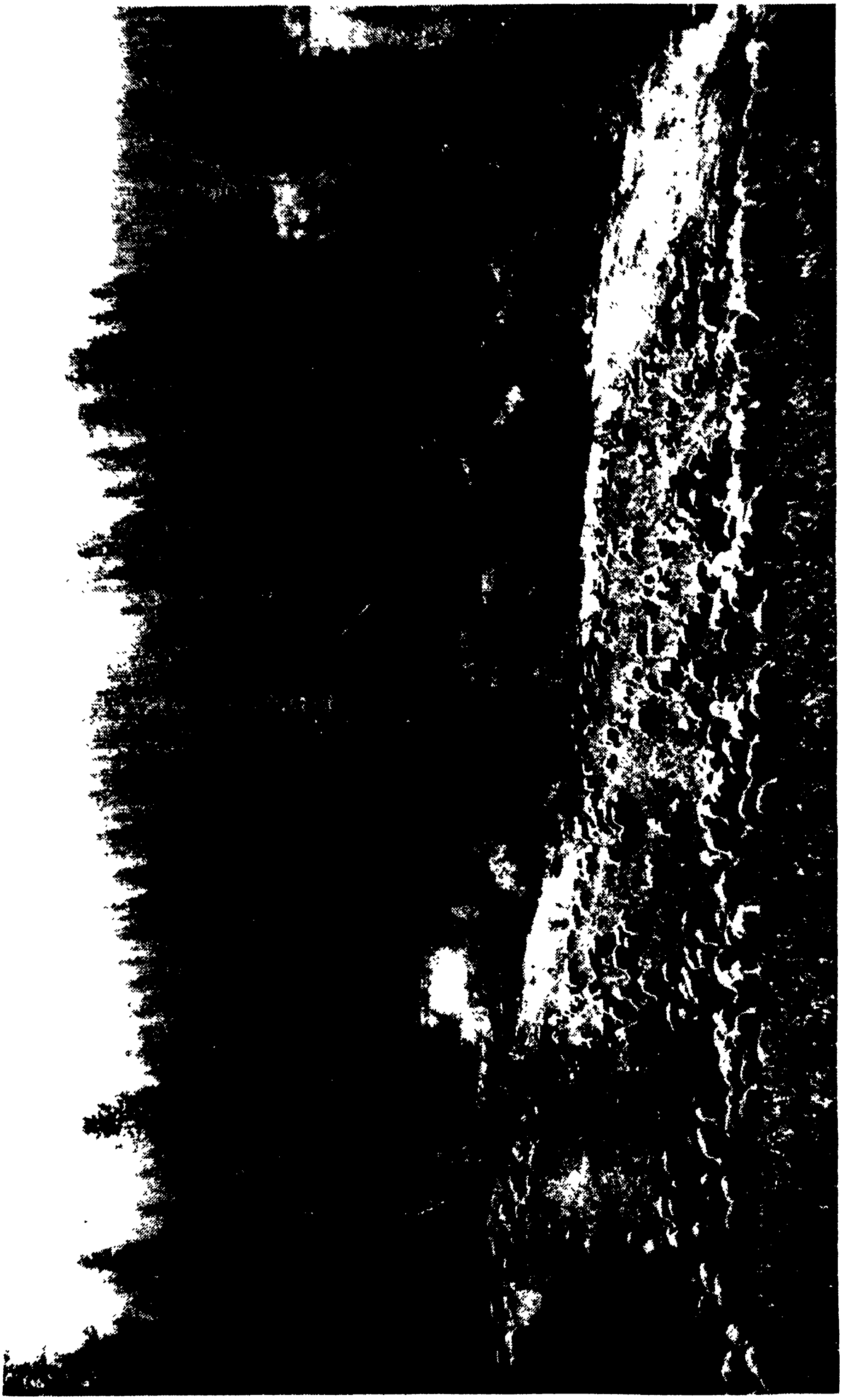

Figure 9.—Summer range conservatively grazed provides abundant excellent feed for sheep with adequate range conservation.

same station Lantow (*661*) reported that feeding from ½ to 1 pound of cottonseed cake a head daily gave best results with calves on winter range—the rate of feeding depending on the quality of the range. A supplement of 1 pound of cake a head daily was adequate for yearlings.

Black and Mathews (*111*) showed that it is much more economical to winter yearling steers on range in the northern Great Plains with a supplement of concentrates or dry roughage when the weather is severe, than to winter them in a lot on harvested feeds.

Management that sustains forage production is of benefit to the stockman as well as to the economic welfare of the West generally. Overgrazing necessitates excessive use of supplemental feed, especially during droughts when hay and other available feeds are apt to be at a premium. The only alternative is starvation losses or forced shipments of livestock on markets depressed by many such efforts to dispose of surplus animals. Sustained livestock production on the basis of conservative grazing and other phases of good range management reduces the unit cost of production and assures more profit to the stockman (*243*).

SOUTHERN FOREST RANGES

The range picture would not be complete without reference to the extensive forest lands of the South producing native forage that is grazed. These forests of the South comprise some 200 million acres, most of which is grazed to some extent. Little attention is given to livestock on unfenced forest ranges, but fires set to "burn off the rough" often damage forest values. Intensive livestock raising as well as intensive forest management will demand independent use of land for the best development, but at present there are large areas of forest land on which grazing and forestry might well be combined under extensive management. Grazing should ordinarily be eliminated from hardwood forests, where feed values are low and reproduction is apt to be damaged severely.

Through proper coordination of grazing of piney woods range with improved pastures and harvested feed, and by improving the type of cattle, livestock production could more nearly meet the milk and meat requirements of the region, and aid living standards of the farmer-stockmen. On cut-over pinelands of southern Mississippi it has been found that the abundant native forage available while the pine reproduction is developing has fairly good feed values in the spring and early summer (*1176*). Cattle make reasonably good gains during that period, but when left on the land until late in the fall or throughout the year without supplements, as is the common practice, they lose this weight. By removing the livestock in the fall to improved pastures, which can be rather readily established on the limited area of highly productive soils, gains in weight and satisfactory calf production could be attained. Needed management features include control of grazing through fence laws, leasing of range privileges on private lands, and other means for placing responsibility on owners of lands and livestock that will aid in overcoming the promiscuous burning and widespread unrestricted grazing now prevailing.

Although there is much general information on the nutritive values of range forage and some very good work is under way, the detailed knowledge of nutritive values of range plants and of management requirements based thereon which will make possible most satisfactory range and livestock management on both western and southern ranges is still lacking.

RESEARCH ON THE EFFECTS OF SOIL AND FERTILIZERS ON PASTURES[5]

To research workers it is apparent that the nutritional values in herbage are modified by a complexity of physical and biological factors concerning which, particularly as to their interrelationships, present knowledge is inadequate.

Pasture species, for example, vary structurally and inherently, not only as species but within each species. Various strains of a given species may differ as widely in habits of growth as varieties of wheat or corn. Associated with variability in structure and growth habits among species is a difference in their ability to utilize nutrients in the soil. Much remains to be learned about this selective ability of plants and its relation to chemical composition—much more with respect to the relation between chemical composition and nutritional values. But an increasing volume of literature clearly indicates the existence of these relationships and further research will clarify them.

EFFECTS OF SOIL AMENDMENTS

Since plants vary in their ability to select and utilize different soil nutrients, the type of soil—its physical and chemical composition—apparently plays a basic part in modifying the growth habits and composition of the plants. This emphasizes the importance of intelligent use of soil amendments, such as fertilizers, lime, and inoculants, calculated to provide a suitable soil environment. Very little is known, however, as to what effect any particular fertilizer will have on the mineral content of the same plants grown on different soils.

In general the amount of any fertilizing element in the soil is reflected in the chemical composition of the plant grown on the soil and also in the physical condition of the animals grazed on these plants. Where deficiency in calcium, nitrogen, potash, or phosphorus occurs in the soil and when increased growth results from the application of one of these elements, the increased growth is usually correlated with an increase in the plant of the particular element applied to the soil. Not infrequently the application of a fertilizing element results in an increase in the plant of a constituent other than that applied as a fertilizer. Adding phosphates to a certain soil may affect the amount of potassium in the plants growing on that soil without adding materially to the phosphorus content, while on another soil applications of phosphate may result only in an increase in the phosphorus content of the plant. Instances have been reported in which applications of phosphorus and potash increased the nitrogen content of the plant very materially. On the other hand, applications of nitrogen alone have in some instances reduced the calcium and phosphorus content of grass. The association of bromegrass with clover is known to result in an increase in the protein content of the grass. In general, however, as first stated, the fertilizing elements in the soil are reflected in the chemical composition of the plant.

Vinall and Wilkins (*1168*) report that nitrogen applied to Kentucky bluegrass increased the crude protein 12.34 percent (average of 56 comparisons). The addition of phosphorus and potash also resulted in increased crude protein. When phosphorus was applied as a fertilizer it effected an average increase of 25.64 percent of elemental phosphorus in the herbage, while the calcium was increased 16.67 percent. When nitrogen was applied to white clover its calcium content decreased 10.64 percent, while the addition of phosphorus to white clover produced small increases in crude protein and an increase of 22.22 percent in phosphorus content and 11.9 percent in calcium. Vinall and Wilkins conclude "that if statistical methods are sound these results prove beyond reasonable doubt that the composition of grass may be changed appreciably by applications of fertilizer to the soil on which it is grown."

Work done in Connecticut (*160*) shows that distinct changes in the composition of herbage have been caused by the various fertilizer treatments. The percentage of dry matter, crude fiber, and the more soluble carbohydrates, organic acids, etc., is high in the herbage from unphosphated plots and lowest in that from plots treated with phosphate plus lime or nitrogen. The reverse was true of ash, nitrogen, fat, and potash. Calcium was depressed by the addition of nitrogen and by the omission of phosphate.

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[5] The material in this section applies almost wholly to farm pastures rather than to range lands. Studies to date raise considerable question as to the practical value of using fertilizers on range land. The section is intended primarily for students and others technically interested in the subject.

Midgley (*787*) cites a number of references showing that plants are materially affected by the nature of the soil in which they grow. If the soils are high in available plant nutrients, this is reflected in the chemical composition of the plants and the physical condition of the grazing animals. Cases are cited of pasture areas that are known to produce nutritional disorders because of lack of certain minerals in the herbage, such as calcium, phosphorus, iron, copper, and iodine; in other cases such disorders are due to an excess of certain elements, as fluorine and selenium.

A study of 775 pastures in West Virginia (*923*) and analyses of the soils showed that the most important factors responsible for the poor type of vegetation found there were soil acidity and lack of available phosphorus. Eighty-five percent of the area was found to be in need of lime and 94 percent was deficient in available phosphorus.

The effect of adding phosphates, however, will vary with different soils. Adding phosphates to some soils may decrease the potassium content of plants without adding materially to the phosphorus content, while on other soils applications of phosphate may result in increases in the phosphorus content of the plants.

Wrenshall and McKibbin (*1272*) in a pot experiment found that the phosphorus intake by pasture plants "is not to be wholly attributed to the utilization of readily soluble phosphate. The phosphorus obtained by the plants was in all cases considerably more than could be attributed to decreases in the amount of readily soluble phosphate in the soil. . . . It is suggested that a considerable proportion of the phosphorus obtained by the plants came from the nucleotides (classes of compounds consisting of carbohydrates, certain nitrogen bases, and phosphoric acid) known to exist in the soil. Decomposition of nucleotides would result in the release of phosphoric acid in the soil, thus providing a notable source of phosphorus for plant nutrition and the replenishing of inorganic phosphates in the soil."

In Michigan (*440*) the phosphorus content of both the stems and leaves of alfalfa grown on soil which did not require lime was increased by the application of phosphate alone or in combination with potash. On another soil that required lime, applications of lime and phosphate did not increase the phosphorus content, whereas the addition of lime to one soil type increased the nitrogen content. In some cases very marked differences occurred in the calcium and phosphorus contents of alfalfa grown on different soil types. Alfalfa grown on heavy-textured soils contained more nitrogen and less phosphorus than that grown on light-textured soils.

The Utah Agricultural Experiment Station (*928*) found that, on a calcareous soil high in total phosphorus but low in available phosphorus, wherever the use of manure or phosphorus fertilizers gave an increase in yield of alfalfa it also gave a marked increase in its phosphorus content. Samples from the Uintah Basin Experiment Farm showed no response to the use of phosphorus either in yield or in phosphorus content of the alfalfa, though some other trials in the same general locality showed an increase in yield. The phosphorus content of this alfalfa was not high as compared with many other samples tested.

Sewell and Latshaw (*1028*) found that on an acid Cherokee silt loam from southeastern Kansas phosphorus alone did not increase the percentage of phosphorus in alfalfa but phosphorus and lime did. The calcium increased in proportion to the amount of lime applied. The various lime and phosphorus fertilizer treatments had little effect on nitrogen content. With an increase in rate of liming a decrease was shown in the percentage of potassium in the dry matter.

Nitrogen, phosphorus, and potassium fertilizers applied alone or in combination to western Washington soils (*1163*) in most cases had no appreciable effect on the percentage of those elements in the alfalfa, but when they were applied to eastern Washington soils the phosphorus and potassium contents of the alfalfa had a tendency to increase as a result of phosphate and potash fertilization. The calcium content did not seem to be affected by fertilization but varied inversely with yield. On an average, alfalfa from eastern Washington contained the highest percentages of nitrogen and calcium and that from western Washington the highest percentage of phosphorus.

In work in Wisconsin (*822*) it was found that nitrogen fertilizers lowered the calcium and phosphorus content of Kentucky bluegrass while the nitrogen content varied directly with the amount applied. Kentucky bluegrass receiving 1,160 pounds of sulfate of ammonia per acre produced 4.44 times more crude protein than grass not fertilized with nitrogen. Phosphate fertilizers increased the phosphorus content, while phosphorus and potash increased the nitrogen content.

Emerson and Barton (*330*) found that the amount of potassium taken up by red clover from a soil varied with the treatment applied. Application of manure increased the solubility of potassium and the amount taken up by the plants.

Adams and others (*14*), studying the effect of fertilizers on the composition of soybeans, found that certain fundamental relationships are indicated:

"(1) The CaO and nitrogen contents of the forage are in proportion to the phosphate applied; (2) the K_2O content varies with the sulfate of potash and indirectly with the phosphate used; (3) the P_2O_5 content is a reflection of the potash and phosphate in the fertilizer, with the former dominating; and (4) the relation of calcium and potassium depends on the level of nitrogen, phosphate, or potash offered to the plant by the fertilizer."

The Kentucky Experiment Station (*620*) made complete analyses of 34 samples of lespedeza hay from different localities in the State. All of the hay from the poorer soils was low in phosphorus and unusually low in protein, whereas hay from the better soils was much higher in phosphorus and protein.

Annual and perennial lespedeza grown on the State Experiment Station farm at Lexington, Ky., contained 0.80 and 0.62 percent of phosphorus pentoxide, respectively, while plants of the same maturity harvested from an unproductive soil on the western substation at Princeton contained only 0.28 percent (*619*).

West Virginia (*924*) reports that herbage from unproductive soil was only 60 percent as high in phosphorus as herbage from more fertile soils. The percentage increase of phosphorus in broomsedge when treated with phosphate fertilizer was approximately the same as in bluegrass similarly treated. Lime increased the percentage of calcium in broomsedge an average of 19 percent, while the calcium content of Kentucky bluegrass increased 36 percent.

Lipman and Blair (*690*) report that liming increased the percentage of nitrogen in alfalfa grown in New Jersey.

In an experiment in southern Illinois, Snider and Hein (*1088*) found that sweetclover contained 35 percent less nitrogen and 67 percent less phosphorus per acre on soil receiving lime alone than on soil receiving lime, phosphorus, and potassium.

On certain soils in the West applications of sulfur are essential to satisfactory yields of alfalfa, indicating that this element is not present in amounts required by the crop. On the other hand, some other crops are not benefited by such treatment. Whether this means that these plants do not take up sulfur or that enough is present in the soil to meet the limited demands is not known.

Studies conducted by the Washington Experiment Station (*839*) indicated that the application of sulfur where needed, as shown by increased yields of legumes, resulted in an increase in nitrogen as well as of sulfur in the plants.

On some of the muck soils in Florida, light applications of copper are very beneficial to alfalfa. It is known that where selenium is present in the soil certain forage plants take up enough of this element to poison livestock, while other plants grown on the same soil take up very little if any. Instances have been reported in which light applications of boron have benefited alfalfa, but where boron is present in excessive quantities it is injurious to plant growth.

CORRELATION OF FORAGE AND ANIMAL YIELDS

Forage yields are difficult to measure or evaluate since such yields must be determined by indirect methods and interpreted in terms of animals or animal products. Experimental technique for measuring pasture yields has not been developed to eliminate experimental error as in other fields of research. Efforts are being made to develop methods which would not require extensive land areas and a large number of animals with the object of determining the value of pasture herbage in terms of animal products.

In a preliminary report of the 5 years' work at Kylertown, Pa. (*408*), in which pasture yields have been determined by calculating the total digestible nutrients in the herbage yields and the total digestible nutrients required by the grazing animals for gain in weight and milk produced, it is stated:

"If the yield of clippings is considered as 100 percent, or the true yield of the pastures, the grazing animals utilized 70 to 80 percent of the T. D. N. (total digestible nutrients) available."

A similar study in West Virginia (*976*) showed a ratio between herbage harvested and total digestible nutrients, calculated from grazing animals, of 1:0.61. While these relative yields do not correspond with those from Kylertown, Pa., the difference may be due to the fact that the pastures in West Virginia were continuously grazed while those in Pennsylvania were rotation-grazed.

Results obtained at Beltsville, Md., as indicated in unpublished data, are in general agreement with Pennsylvania results with one exception—the yield of herbages obtained from a pasture which contained a high percentage of annual lespedeza as estimated from hand-harvested plots was less than that estimated to have been obtained by grazing animals. These differences indicate the need for further study on the effect of grazing management on forage yields.

THE NUTRITIVE VALUE OF HARVESTED FORAGES

by T. E. Woodward, W. H. Hosterman, P. V. Cardon, and E. W. McComas[1]

HERE is a thorough discussion of the factors affecting the nutritive value of harvested forage; the methods of harvesting, processing, and storing; haymaking and the kinds and grades of hay; the making of silage and the effects of acidity, temperature, and moisture on its quality; and the right use and the limitations of harvested forage as livestock feed.

THE AVERAGE annual value of the hay produced in the United States in the 10 years 1928-37, was about 765 million dollars—more than that of any other crop except corn. The comparative value of cotton was 98 percent and that of wheat 82 percent for the period. Silage, the other harvested forage discussed in this article, had a value of 100 million dollars or more.

The most important crops used for hay ranked as follows in average tonnage per year for the decade 1928-37: (1) All clover and timothy, (2) alfalfa, (3) wild hay, (4) soybeans, cowpeas, and peanut vines, (5) small grains, (6) sorgo, (7) lespedeza, and (8) sweetclover. During the entire period the tonnages of alfalfa, soybeans, and lespedeza increased and those of timothy and clover and of wild hay decreased, but for the 3 years 1935-37 the ranking remained unchanged except that alfalfa took first place, ahead of all clover and timothy.

The principal reason for harvesting forage is to provide feed for livestock during seasons when there is a shortage or complete lack of growing herbage. Less important reasons are to prevent waste through trampling and soiling and to put the forage in a commercial form. In the process of harvesting the forage it always loses some of its nutritive value. The loss may be slight, or it may be 50 percent or more, depending on the methods used and on the weather. Some English investigators estimate that under the conditions prevailing in the British Isles an average of about 40 percent of the nutritive value of a crop is lost when it is made into hay. In the United States such a loss would appear excessive, but there is insufficient information to permit a reliable estimate. So far as is known, harvested forage is superior to the fresh, green forage in only one respect—sun-cured forage contains greater quantities of vitamin D. Any system of harvesting and curing forage has for its objectives keeping the losses of nutrients low and the cost nominal.

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Hay is by far the most important form of harvested forage, because it does not deteriorate rapidly in storage, it can be handled commercially, and it can be made without great expense for labor, machinery, and buildings. When, as sometimes happens, the character of the crop or the weather is such as to preclude the making of good-quality hay, the use of the silo offers a satisfactory way of saving the forage for home consumption by certain kinds of farm animals.

As a rule a crop cannot be harvested and stored as cheaply in the form of silage as in the form of hay. Offsetting this disadvantage, partly or wholly, is the fact that if it is properly made the silage generally retains a greater proportion of the nutritive value of the green plant. The principal use of the silo, however, is to save forages which would otherwise be largely wasted, damaged, or lost entirely.

Another way to save the forage in spite of the weather is to dry it artificially. This practice, if properly carried out in a good type of drier, preserves the crop with the least change and the least loss of nutrients, but it is too expensive as yet for the average individual farmer, though it may be practicable for groups of farmers.

The principal silage crop is corn. In 1937, 35 million tons of corn silage was made. Considerable quantities of sorghum, small grains, grass, and corn fodder also are put into the silo, but no statistics on these are available. Apparently by exercising proper precautions any of the forage crops can be successfully preserved in the silo.

The nutritive value of a crop is measured by its (1) yield, (2) palatability, (3) composition, (4) digestibility, and (5) physiological effect upon the animal. The yield is important because of the fixed charges in raising a crop. The net returns from a large yield are naturally greater than those from a small yield. No characteristic of a plant is more important than palatability, because if livestock will not eat a plant it is useless for feeding. Palatable feeds are eaten in larger amounts than unpalatable feeds. Where a maximum consumption is desirable, as with fattening animals or high-producing dairy cows, palatability has a direct relationship to economy of production. The composition of plants indicates the amounts of useful nutrients they contain and whether there is likely to be a deficiency of any essential constituent. The digestibility is important because it is only that portion of the feed which is digested that can be utilized physiologically. Fortunately, most feeds have no unfavorable physiological effect upon the animal. Poisonous plants are usually avoided by animals, either because of instinct or because the taste or smell is objectionable to them, and unsound or spoiled feeds which might cause injury are likely to be unpalatable. Poorly fed, hungry animals are the ones most likely to eat harmful feeds.

In the following pages the different plants, the conditions affecting their growth, and the methods of harvesting and conditions of storage will be discussed in more detail with reference to these five characteristics.

FACTORS AFFECTING THE NUTRITIVE VALUE OF FORAGES

STAGE OF GROWTH

The stage of growth of plants has come to be recognized as one of the most important considerations in the harvesting of forage crops. The more immature a crop of forage is when cut the smaller will be the yield and the more nutritious the product. But small yields and frequent cuttings increase labor costs. Some sacrifice of quality must be made in the interest of greater yields and greater economy of harvesting. Usually, therefore, plants are harvested for hay or silage at an intermediate stage when neither the yield nor the quality is at its maximum. Because of the greater water content of young plants and their tendency to pack together when mowed, they do not dry as readily as more mature plants. Taking into consideration the yield, quality of hay, composition, effect upon the stand, and labor of harvesting, the best time to harvest the grasses, clovers, and alfalfa for hay is ordinarily sometime between early bloom and full bloom. Crops which are heavy producers of seed, as the cereals, soybeans, and cowpeas, should be cut at a later stage—cereals when the grain is in the soft or dough stage, soybeans when the beans are about half grown, and cowpeas when the first pods are mature. When a hay of very high quality is required, the grasses and alfalfa are sometimes harvested before they bloom.

The palatability of young plants is almost invariably superior to that of more mature plants. Waters (*1184*) [2] demonstrated many years ago that timothy hay cut at the bloom stage was more palatable to both steers and dairy cows than hay cut at the seed stage. Young plants are tenderer, the proportion of leaves is higher, and the hay made from them is softer, all of which make for greater palatability.

Probably the most striking characteristic of stage of growth is the change in composition with advance toward maturity. The contents of protein and minerals are higher and that of the less valuable crude fiber is lower in young plants than in older plants. These changes in the composition of alfalfa are well shown in table 1, from work done by Kiesselbach and Anderson (*626*). Similar information for timothy by Trowbridge et al. (*1150*) is given in table 2.

TABLE 1.—*Effect of the time of cutting upon the chemical composition of alfalfa hay, average for 4 years 1921–24*

Stage of maturity	Ash	Protein	Fiber	Nitrogen-free extract	Fat
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Prebloom	11. 24	21. 98	25. 13	38. 72	2. 93
Initial bloom	10. 52	20. 03	25. 75	40. 67	3. 03
One-tenth bloom	10. 27	19. 24	27. 09	40. 38	3. 02
One-half bloom	10. 69	18. 84	28. 12	39. 45	2. 90
Full bloom	9. 36	18. 13	30. 82	38. 70	2. 99
Seed stage	7. 33	14. 06	36. 61	39. 61	2. 39

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[2] Italic numbers in parentheses refer to Literature Cited, p. 1075.

TABLE 2.—*Composition of the dry substance of timothy hay harvested at different stages of maturity*

Stage of maturity	Protein	Ether extract	Crude fiber	Ash	Nitrogen-free extract
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
1 foot high, no heads showing	10.18	4.61	26.31	8.41	50.49
Beginning to head	8.02	4.07	31.15	7.61	49.14
Full bloom	5.90	2.38	33.74	6.10	51.89
Out of bloom; seed found	5.27	3.13	31.95	5.54	54.12
Seed all in dough	5.06	2.87	30.21	5.38	56.48
Seed fully ripe	5.12	2.72	31.07	5.23	55.87

The crude fiber of the young plant growth as in immature pasture herbage appears to be practically as digestible as the nitrogen-free extract. As the plant matures, a progressively greater proportion of the crude fiber is made up of lignin which, besides being indigestible itself, increases the energy expenditure for mastication and digestion of the feed and lowers its net nutritive value. Phillips and Goss (*919*) analyzed the barley plant at 7-day intervals for lignin and related compounds. Presumably the following figures, which show the extent to which the lignin, calculated on the basis of oven-dried material, increases with advance toward maturity of the barley plant, will apply in a general way to other species of plants:

Age of plants (days)	Lignin content (percent)	Age of plants (days)	Lignin content (percent)	Age of plants (days)	Lignin content (percent)
7	1.48	42	3.49	70	6.93
14	1.71	49	5.10	77	6.97
21	2.31	56	5.93	84	7.34
28	2.50	63	6.80	86	7.74
35	2.88				

The carotene content of plants in their early stage of growth exceeds that of more mature plants, because leaves contain more carotene than stems and the leaves of an immature crop are all green, whereas with advance in stage of maturity some of them become yellow or brown. If the hay is to be field-cured in the ordinary way, it is unlikely that the carotene content of the crop at time of harvesting is a factor of much importance in the determination of the date of harvesting, since by far the larger portion of the carotene is lost in curing even under the most favorable conditions. If the crop is to be artificially dried or made into silage, then the carotene content of the crop at time of harvesting assumes greater importance, because one reason for artificial drying or siloing is to preserve more of the carotene than is possible by field curing.

LEAVES VERSUS STEMS

The leaves of all forage plants are greatly superior to the stems in nutritive value. Table 3, containing data from Sotola's work (*1090*), shows the difference in composition and digestibility of alfalfa leaves and stems. These differences are similar to those in other plants. The leaves are superior in composition because they have higher percentages of the more valuable constituents and a lower percentage of the less valuable fiber. The digestibility is also markedly superior. It is evident, therefore, that any method of harvesting, handling, or storing forages that increases the proportion of leaves to stems increases the nutritive value.

TABLE 3.—*The composition and apparent digestibility of alfalfa stems and leaves,*[1] *average of first, second, and third cuttings*

Item	Dry matter	Protein	Crude fiber	Fat	Ash	Nitrogen-free extract	Calcium	Phosphorus
Stems:								
Composition...percent..	87.27	8.17	41.59	1.30	5.42	33.52	0.86	0.13
Coefficient of digestion...	46.6	51.1	39.0	47.9	27.5	58.9	[2] +1.29	[2] +.50
Leaves:								
Composition...percent..	86.33	19.57	16.47	3.01	9.43	41.88	2.76	.22
Coefficient of digestion...	66.3	77.4	55.5	29.7	34.6	75.9	[2] +24.22	[2] +7.32

[1] The total of digestible nutrients in the stems was 41.53 percent and in the leaves 58.09 percent.

[2] Gram intake by sheep in feed minus gram outgo in feces and urine—average per day per sheep

While the early-cut hays do have a higher percentage of leaves, as is shown in table 4, their superiority can be explained only in part by the leaf-stem ratio. In alfalfa and presumably in other legumes, the ratio of leaves to stems changes but not to a marked extent until the plant becomes sufficiently mature to begin to lose some of its leaves. The data in table 4 do not take into account the losses of leaves which occur in the curing and storing of hays. The percentages given for the leaves are higher than are actually found in the cured hays, and especially is this thought to be the case with the hays harvested at the more mature stages.

TABLE 4.—*Percentage of leaves in alfalfa hay harvested at different stages of growth, in Kansas (999) and Nebraska (626)*

Kansas		Nebraska	
Stage of growth	Leaves	Stage of growth	Leaves
	Percent		*Percent*
Bud stage...	53.4	Prebloom...	57.3
One-tenth bloom...	51.1	Initial bloom...	56.6
Full bloom...	48.4	One-tenth bloom...	55.8
Seed stage...	41.6	One-half bloom...	53.2
		Full bloom...	49.4
		Seed stage...	33.3

TABLE 5.—*Protein and fiber content (dry-matter basis) of leaf and stem at the prebudding, budding, and early-flowering stages of alfalfa*

First cut at—	Howe Hill (1933)				Willingham (1933)			
	Leaf		Stem		Leaf		Stem	
	Crude protein	Crude fiber	Crude protein	Crude fiber	Crude protein	Crude fiber	Crude protein	Crude fiber
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Prebudding stage...	30.13	12.99	16.97	30.77	32.93	12.47	19.46	30.94
Budding stage...	27.45	12.33	12.48	42.46	28.38	13.19	13.57	42.88
Early-flowering stage...	23.48	13.39	9.44	44.36	24.57	13.94	11.03	46.49

The change in composition of both the leaves and stems through advance in stage of maturity may have a bearing on the nutritive value of the hay fully as important as the change in leaf-stem ratio. Data supporting this view are shown in table 5, taken from a report of Woodman and Evans (*1258*).

It appears that the proportion of leaves to the other parts of the hay may be more important with at least some of the grasses than it is with the legumes because of the greater range in variation. For example, Hosterman and Hall (*544*) found that the leaf blades and sheaths of timothy at a stage when nearly fully headed made up 61.4 percent of the total weight, whereas at a stage when the heads were mature they made up only 21.2 percent of the total. The extreme range in leaf content was not only greater than with alfalfa (table 4), but the range within which most of the hay is harvested was also greater. Table 6 shows the proportions and analyses of the different parts of timothy hay when harvested at different stages of maturity.

TABLE 6.—*Proportion of leaf blades, leaf sheaths, stems, and heads in timothy hay cut at different stages of maturity, and the protein, ether extract, and crude fiber in each part, on oven-dry basis*

Stage of maturity	Proportion of total weight	Protein	Ether extract	Crude fiber
	Percent	*Percent*	*Percent*	*Percent*
LEAF BLADES				
Nearly fully headed	38.2	11.6	4.8	24.3
Early bloom	29.3	11.6	4.6	25.1
Just past full bloom	20.5	11.0	5.1	25.0
10 percent of heads straw-colored	11.5	9.0	5.4	25.0
Heads mature	10.0	6.6	5.4	25.9
LEAF SHEATHS				
Nearly fully headed	23.2	5.4	1.4	34.1
Early bloom	19.9	5.7	1.9	36.0
Just past full bloom	15.7	6.2	2.0	35.6
10 percent of heads straw-colored	12.9	7.4	2.7	35.8
Heads mature	11.2	6.1	3.0	35.3
STEMS				
Nearly fully headed	26.6	4.4	.9	33.8
Early bloom	33.0	4.8	.8	39.7
Just past full bloom	47.1	3.2	.8	40.7
10 percent of heads straw-colored	45.7	2.9	1.1	43.0
Heads mature	38.7	2.8	1.3	41.6
HEADS				
Nearly fully headed	12.0	12.8	2.4	29.7
Early bloom	17.8	12.5	8.3	30.7
Just past full bloom	16.7	12.2	3.1	28.0
10 percent of heads straw-colored	29.9	12.2	3.6	21.5
Heads mature	40.1	13.8	3.2	15.6

CLIMATE

The climate affects the yield more than it does the composition. The disastrous consequences of drought are well known. Not only may the yields be greatly reduced by drought, but the nutritive value may be impaired in some respects. Dry weather tends to lower the phosphorus content of plants, as shown by Browne (*164*) in the 1938 Yearbook of Agriculture; it may reduce the carotene content also if the herbage dries and weathers enough to lose its green color. An excess of rain while the forages are growing is less common than a shortage of rain. As a rule wet weather increases the yield, but it may lead to the development of heavy stems. Furthermore, heavy rains may cause the crop to go down or lodge. By shutting off the light from the lower portion of the crop lodging may cause some of the leaves to drop off and by keeping it moist may cause considerable spoilage.

SOIL

In general, it may be said that all plants have a composition which is inherent to that particular species or variety. If the soil contains in available form and in sufficient quantity all of the essential minerals for the growth of the plant and the climatic conditions are favorable, the plants will have a normal composition and the further addition of essential minerals in the properly balanced proportions will generally affect but little the chemical composition of the plants. On the other hand, the deficiency in the soil of any element used by the plant is likely to result in a deficiency of that element in the plant. For this reason proper attention to the needs of the soil will go far toward assuring a normal composition of the plants and satisfactory nutrition of the livestock that consume the forage grown on the soil. The addition of calcium, phosphorus, nitrogen, and iodine to soils deficient in these elements has been shown to increase the contents of them in the forage. Presumably the same will occur when copper, iron, and cobalt are added to the soil, since deficiencies of these elements in the feed also have been traced to deficiencies in the soil.

Selenium is one element that has been used by plants in a certain section of the West in amounts sufficient to be toxic to the animals consuming them.

While deficiencies of minerals in the forage may be corrected by treatment of the soil, it is often more satisfactory as well as more economical to administer or feed some kinds of minerals directly to the animal. Furthermore, some forages may not contain enough of some of the mineral elements for certain types of production even when grown on soils adequately supplied with all minerals. In such cases the minerals that are lacking must, of course, be fed directly or supplied in supplementary feed. For further information on the relation of minerals in plants to minerals in soils the reader is referred to articles in the 1938 Yearbook by Browne (*164*) and by McMurtrey and Robinson (*737*).

SPECIES—LEGUMES AND NONLEGUMES

The species of plants used for forage have an important bearing on the nutritive value. Forage plants may be roughly divided into legumes and nonlegumes. Legumes are characterized in general by a relatively high content of protein and calcium and by the fact that their leaves readily become detached from the stems when dry. Because of their high content of protein and because they improve the nitrogen content of the soil few livestock farmers can profitably avoid growing them.

Alfalfa is the most important of the legumes grown for hay in the United States. It is a perennial, yields heavily, and makes a very palatable and nutritious hay. Red clover perhaps ranks next in popularity. It can be grown successfully on many soils where alfalfa does not thrive, and along with timothy it makes one of the principal hays of the United States. It is not equal to alfalfa in yield per acre or palatability, and because of the more advanced stage of maturity at which it is usually harvested it does not contain as much protein. Soybeans perhaps rank next in importance among the legumes. The acreage of soybeans keeps increasing steadily, probably because they are a relatively sure crop, can be grown on a wider variety of soils than alfalfa or red clover, and can be utilized either for seed or hay. Unless harvested early while the days are long and the weather is warm, they are not only difficult to cure but the stems will become so woody that they will be refused by livestock. Good soybean hay ranks close to alfalfa in feeding value. Cowpeas are grown only in the southern part of the United States; in growth habits and feeding value they are similar to soybeans. Alsike clover makes a hay that generally is superior to red clover hay in color. In other respects the two clovers are much alike except that alsike does not yield as well as red clover. Lespedeza is coming into favor because it will thrive on land that has a low content of lime and because the seed is relatively inexpensive. The low moisture content of the stems makes it one of the easiest legumes to cure. Hay made from the annual lespedezas is palatable, finer stemmed than alfalfa, and not far behind it in feeding value, though the content of protein is somewhat less on the average. The annual lespedezas will not thrive in the more northerly regions of the United States.

Mammoth red clover, crimson clover, peanut vines, and kudzu are other legumes of less importance for hay. Sweetclover must be cut early before the stems become thick and woody, otherwise there will be excessive waste in feeding. The hay must also be well cured, as unsound (moldy) sweetclover hay may develop a substance that interferes with the normal coagulation of the blood, which may lead to fatal hemorrhages of the animals eating the hay if it is fed exclusively for more than 10 to 15 days.

Of the nonlegumes timothy is easily the most important. It grows on a wide variety of soils in the northern part of the United States and, in New England especially, appears to be almost indigenous. It is an excellent grass to seed with wheat as it can be seeded at the same time and with the same implement. If timothy is harvested at the early-bloom stage or before, it will make a hay that compares favorably with average alfalfa hay in palatability and also in feeding value, except that it will have a lower content of protein and calcium.

The prairie hays of the West rank second in importance among the nonlegumes. These hays are made up of grasses, some of which are much more nutritious than others. Upland grasses such as the bluestems make the best kind of prairie hay. In composition and feeding value such upland hay is similar to timothy hay.

Small-grain hays, followed by sorgos, including Sudan grass, rank next in tonnage produced in the United States. Small grains, particularly oats, are used for hay principally in the Pacific Coast States and in the northern Great Plains but also to some extent in other parts of the country, while sorgos are used mainly in the Great Plains. The stems in the small-grain hays are somewhat unpalatable, but this disadvantage is offset by the high nutritive value of the grain. Sorgos, although having a low protein content, make very good hay if cut early before heavy stems have developed and if they can be cured without spoiling. Prussic acid may form in the new growth of Sudan grass, Johnson grass, and the sweet sorghums following a drought or frost. While most cases of poisoning from this chemical develop in livestock eating the green forage, there have been instances of fatalities following the eating of hay made from the poisonous green forage. The sedges and rushes of the Rocky Mountain States, Johnson grass, red top, bromegrass, quackgrass, Bermuda grass, orchard grass, Kentucky bluegrass, crested wheatgrass, and crabgrass, are other plants more or less used for hay. They all make acceptable hays if cut early and cured without damage.

Mixtures of legumes and nonlegumes are quite commonly used for hay. Timothy and clover, timothy and alfalfa, oats and peas, oats and vetch, Sudan grass and soybeans, alfalfa and a voluntary growth of Kentucky bluegrass or crabgrass, and a mixture of alfalfa, timothy, and clover, are familiar examples. The legumes in such mixtures are advantageous in that they increase the protein and lime content of the forage and provide nitrogen for the growth of nonlegumes; the nonlegumes are advantageous in that they are likely to be surer crops than the legumes, and if the legumes fail the nonlegumes are left to provide some forage. In some cases the different kinds of plants make most of their growth at different times in the season or in different seasons. There is no apparent advantage in this characteristic if the crop is to be harvested for hay or silage, but there may be an advantage if it is to be pastured. In timothy-clover mixtures the forage the first year after seeding is mainly clover, while the second year it is mainly timothy.

Mixtures are desirable in that they usually increase the yield per acre, and there is some evidence that a mixture of legumes and nonlegumes makes a more complete ration from a nutritive standpoint than either alone. The tendency at present appears to be toward mixtures rather than single crops, though in the case of alfalfa this tendency is shown only in those places less favorable to the growth of alfalfa or where the alfalfa is to be pastured. Timothy, orchard grass, and bromegrass appear to be the grasses most favored to seed with the alfalfa. When the grasses do not reach the proper stage for harvesting at the same time as the alfalfa, as is usually the case, harvesting should be at the time considered best for the alfalfa rather than for the grasses.

Generally speaking, the stage of growth of the herbage and the method of curing exert more influence upon the feeding value of hay than does the species or variety of plants from which it is made. A good hay of any species or variety is likely to be better than a poor hay of any other species or variety. This statement does not apply, of course, to plants that are naturally unpalatable and are not usually made into hay.

DISEASES AND INSECTS

It is well known that diseases and insects reduce the yields and may in some instances practically destroy a crop. It is not known how much they affect palatability and composition. Any disease or insect attack that reduces the proportion of leaves to stems lowers the nutritive value, and any disease that leads to a discoloration of the foliage reduces the content of carotene in the crop. Dairymen discriminate against alfalfa hay from southern California that has been severely attacked by the alfalfa web worm, as this pest is known to injure the palatability of the hay. It is certain, therefore, that diseases and insects may lower the nutritive value and reduce the palatability, but whether they cause changes in the plant detrimental to the health of animals that eat them is still an unsettled problem.

Molds or mustiness developed in the process of curing or storing may be harmful, especially to horses and sheep. When fed to horses musty hay is likely to cause heaves and moldy hay may cause more serious trouble, while cattle appear to be to a large extent immune to the effects of molds. Any growth of mold is always at the expense of useful food constituents. Even if the molds do not cause any injury to the health of the animals, they reduce the palatability of the forage. Conditions favoring the growth of molds also favor the destruction of carotene; moldy hays are low-carotene hays.

EFFECTS OF METHODS OF HARVESTING, PROCESSING, AND STORING

SOME OF THE CHANGES THAT TAKE PLACE IN THE CURING AND STORING OF HAY

When crops are harvested there is an inevitable loss of nutrients. Apparently the carotene starts to disappear at once. It has been found that alfalfa exposed in the swath and windrow from the morning of one day to the afternoon of the next day (about 30 hours), during good hay-curing weather, may lose 60 to 65 percent of its carotene. Even immediate drying by artificial means fails to preserve all of the carotene. Artificially dried hay may contain only about one-half as much carotene as the fresh, green crop, the amount depending to a considerable extent upon the conditions of storage and the length of time in storage after drying. Furthermore, the drying of green material either artificially or naturally reduces the content of nitrogen. Probably the nitrogen compounds that are lost by drying rather than by biological processes through the action of enzymes and micro-organisms are so simple in composition as to be of little nutritive value.

The destruction of carotene appears to be due chiefly or solely to oxidation. Fresh vegetables preserved and stored in the absence of air, as when canned, retain most or all of their carotene. Feeds preserved in containers from which air is at least partly excluded (silage) retain much more of their carotene than if they are exposed to air. While perfect preservation of the carotene can be attained only by the complete exclusion of oxygen or air, there are certain factors which in the presence of air accelerate or retard oxidation. It is possible, therefore, by properly employing these factors, to preserve more or less of the carotene for an indefinite period even in the presence of oxygen, as in the making and storing of hay.

The Indiana Agricultural Experiment Station (*571*) reports some investigations which show that destruction of carotene takes place through the action of oxidative enzymes and that the activity of these enzymes is influenced by the moisture and temperature. For example, young alfalfa was treated in a way to inactivate the enzymes, after which some of it was sun-dried and some was incubated at 38° C. The vitamin A value, as determined by biological assays, was not destroyed. On the other hand, if the young alfalfa was incubated or sun-dried before inactivation of the enzyme, or if an enzyme was added after inactivation and then incubated, much of the vitamin A value was destroyed. The inactivation of enzymes in sun-cured hays does not appear to be practicable, but it has been observed that this knowledge is being made use of in the commercial drying of young grass in England, where the grass passes through a hot-water bath before it is dehydrated.

In the making of hay under practical farm conditions the way to keep the carotene losses at a minimum is to bring the hay to an air-dry condition as soon as possible. The combined influence of moisture and temperature in the presence of air results in the rapid destruction of the carotene. The action of direct sunlight in decolorizing hays wet with external moisture, as dew or rain, is a matter of common observation. As green color and content of carotene are closely associated in the hays, any practice which results in the destruction of the green color results also in reducing the content of carotene.

Figure 1, prepared from unpublished data secured by the Bureau of Dairy Industry at Beltsville, Md., shows the correlation between green color, chlorophyll, and carotene in alfalfa hay. When 50 specimens of hay were arranged in 6 groups according to their color, as determined by the Bureau of Agricultural Economics, the curves representing the contents of chlorophyll and carotene followed the same general course as the curve representing the color. The color was measured as percent of natural green color, which means the percent of the maximum color that has been found in alfalfa hay.

Hay that has not been thoroughly dried either naturally or artificially will heat when it is stored. Field-cured hays almost invariably contain enough moisture when they are stored to go through a sweat. Any heating that takes place results in the destruction not only of carotene but also of other valuable feed constituents. The degree of heat developed and the losses sustained are directly proportional to the moisture content of the material and to the tightness of packing. Loosely packed hay permits the air to circulate more freely and thus facilitates drying and the dissipation of heat. Carotene destruction continues after the hay has reached an air-dry condition but at a much slower rate. Nevertheless, Kane and Shinn (*606*) have found that the loss which would normally occur during the usual storage period of hay is considerable. Alfalfa meals and hays lost 35 to 40 percent of their carotene when stored for 7 to 8 months in a dark barn at temperatures and humidities normally occurring at Beltsville, Md. Corresponding reductions in the green color amounted to only about 13 percent. It is possible, therefore, to have a hay with a good color but with a low carotene content after a long period of storage.

A number of investigations have shown the influence upon the carotene content of the temperature at which hay is stored. Freshly cured hay at Beltsville (*1263*), with a carotene content of 89 parts per million of dry matter, when stored for 6 to 8 months at temperatures of 42°, 20°, and 5° C. (107.6°, 68°, and 41° F.), contained, respectively, 6, 25, and 43 parts per million of carotene. Other hays stored

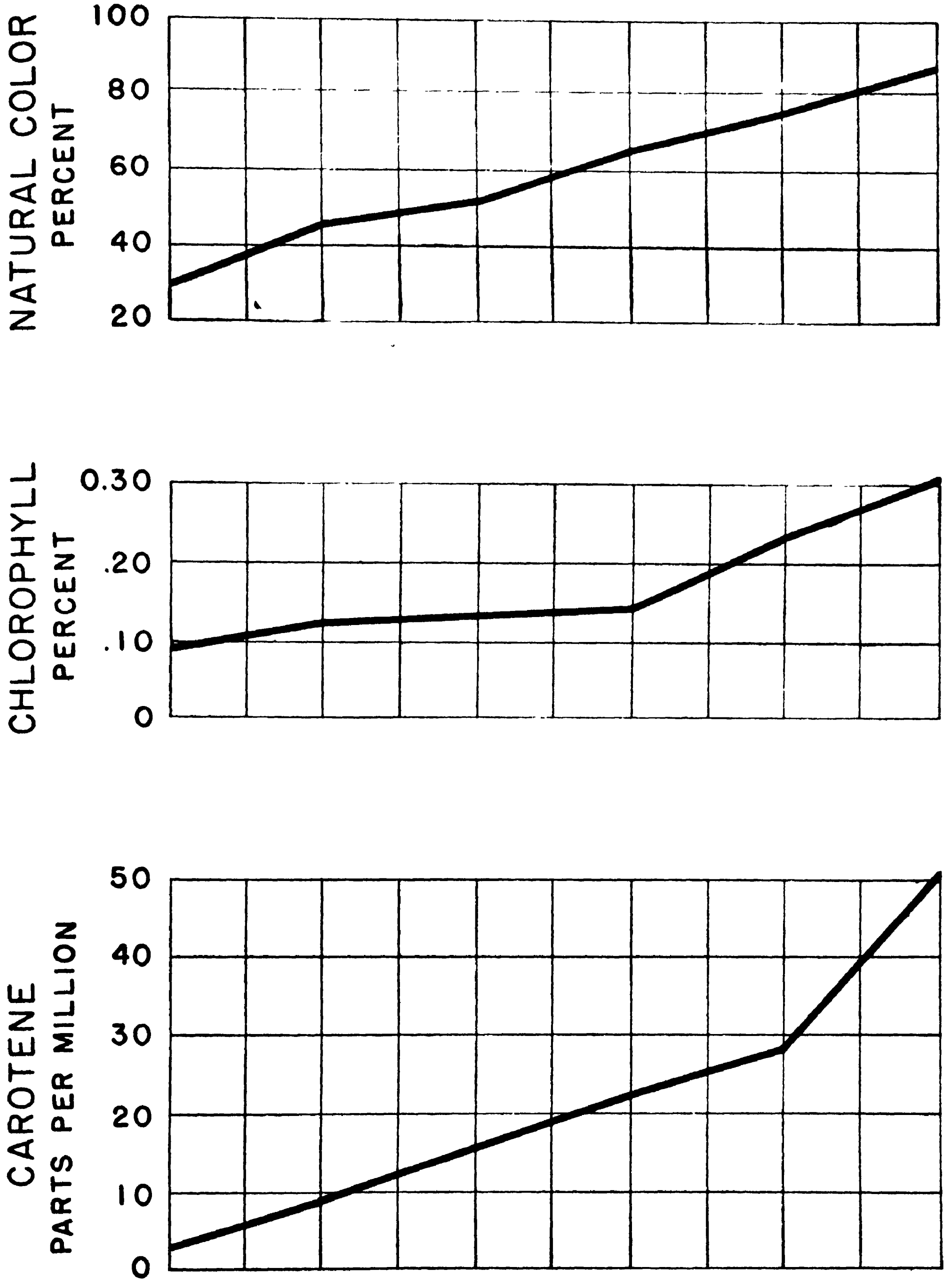

Figure 1.—The relation of chlorophyll and carotene to the green color of alfalfa hay. (Analyses of 50 samples.)

at room temperature and at 5° contained 27 and 40 parts per million of carotene, respectively, after storage. Baled alfalfa (*1243*) stored in the loft of an unheated barn lost 3 percent of its carotene per month in the winter, and 6.5 percent per month in the spring and fall. Samples stored the first summer after harvesting lost 21 percent per month; during the second summer they lost 12 percent per month. When alfalfa hay was stored (*441*) at a temperature below 5° no loss of carotene was detected in 6 months, but the rate of loss increased very rapidly with rise of temperature.

Besides the carotene other feed constituents are lost in the process of harvesting and storing, though usually not to such a great extent. As respiration continues in green plants for some time after cutting, it appears that this must be accompanied by a loss in dry matter. However, if the drying is rapid the loss of dry matter from the time of cutting to storing is only a few percent unless excessive leaf shattering occurs. Furthermore, if the hay is dry enough when stored so that it undergoes only a normal sweat, it will lose only a few percent of dry matter while in storage. It is only when the hay must remain in the field for long periods or when it is stored with too much moisture that the losses become excessive. The weather at the time of harvesting is an important factor in the loss of dry matter.

Watson and associates (*1194*) estimate the average losses in nutritive value (starch equivalent and protein equivalent) for 4 years through harvesting and storing hay in the stack in England at 30 to 40 percent. It should be borne in mind that the weather in England and northern Europe is both cooler and cloudier than in most parts of the United States, also that the rains are more frequent. A common practice is to cock or hang the partially dried hay on racks in a manner to shed the rain and at the same time facilitate aeration and drying. In some parts of England the partially dried hay is put in large cocks (pikes) containing about 800 pounds, where it is sometimes left for 2 weeks or more before it is hauled to the barn for storage. Because of the more favorable weather for the curing of hay in the United States it would appear that an average loss of 30 to 40 percent in nutritive value is excessive. However, it must be recognized that very unfavorable weather for haymaking is likely to occur over most of the United States, especially in the making of hay from spring-harvested crops and in making soybean and cowpea hay in the fall. In addition to the losses resulting from the hay remaining in a moist condition for a long period in the curing and storing there is a considerable loss of leaves from the legumes. Studies with alfalfa in Kansas (*999*) showed that the average loss of leaves for 7 years was 19 percent, which was estimated to represent 9.2 percent of the weight of the total crop. Other studies, in the Platte Valley of Nebraska,[3] indicated a much lower loss of leaves—5.9 percent. Insufficient data are available to permit an accurate estimate of the average losses in nutritive value which occur in the period between the harvesting and feeding of hays in the United States.

The disastrous effects of rain on hay are a matter of common observation, but as yet we cannot estimate the extent of damage from any given amount of rainfall. Guilbert and associates (*446*) carried out leaching experiments on bur clover, oat hay, and naturally cured range forage. The minerals showed the greatest percentage loss, and the loss of phosphorus exceeded that of calcium. The loss of crude protein ranged from 1 to 18 percent of the total, and of nitrogen-free extract from 6 to 35 percent of the total, according to the nature of the forage. Probably the losses in nutritive value due to rain will be manifested to as great an extent in impairment of the palatability and in loss of color as in the loss of nutrients as determined by chemical analyses for the usual feed constituents.

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[3] HOSTERMAN, W. H., KIESSELBACH, T. A., and FROLIK, ELVIN F. ALFALFA HAY MANAGEMENT STUDIES. Prelim. Rept., Bur. Agr. Econ. and Nebr. Agr. Expt. Sta., 36 pp. 1934. [Mimeographed.]

THE SPONTANEOUS HEATING OF HAY

A certain amount of heating and fermentation normally occurs when field-cured hay is stored in the stack or mow. Ordinarily farmers intend to have the hay sufficiently dry at the time of storage so that it will heat only moderately. This heating is popularly called sweating. The temperatures do not become so high as to materially affect the green color or the nutritive value.

When the hay is stored with a moisture content higher than is required to bring about normal sweating, the hay will sustain a marked loss of color and will become gray green to greenish brown, but the palatability and productive value will be affected little if any except as the lower carotene content may reduce the productive value.

A still higher moisture content will cause the hay to become brown or black, in which case all of the carotene is destroyed. The losses of dry matter and of feed nutrients in brown hay may be only a few percent and the palatability may be practically unaffected. However, if the hay becomes black the losses of dry matter and feed nutrients are heavy and the hay has a distinctly lower palatability and productive value. This is well shown by experiments at the Kansas Agricultural Experiment Station (*1112*), where a large stack of hay having a moisture content of 53 percent, in which a large proportion became black, sustained a dry-matter loss of 39 percent. This loss included that due to weathering as well as to heating. Hoffman (*526*) reports that when smaller quantities of hay with 18 to 35 percent of moisture are stored in a mow the losses of organic substance average about 13 percent.

Besides the moisture content, the density and the size of the mass of hay have an influence upon the temperatures developed. Hay stored in narrow mows or bents in a barn or in thin layers will not heat as much as hay stored in wide mows or to a considerable depth because of the freer circulation of air. However, if the former remains moist for a considerable time it becomes musty or moldy.

Bacteria are responsible for most of the heat developed up to the thermal death point of the bacteria. Some may not be killed until the temperature reaches about 170° F. or perhaps even higher. Any further heating is due entirely to chemical changes. A number of theories have been advanced regarding the substances which are formed in the hay through microbial activity and which readily ignite when exposed to air. Spontaneous ignition has been studied in the Bureau of Chemistry and Soils for years, and there are a number of excellent publications on the subject. (See the article Losses in Making Hay and Silage, p. 992.)

SOILING

Harvesting and feeding the crops green is called soiling. Although this practice results in a maximum utilization of the forage, since there is no wastage through trampling, as under grazing, and no considerable loss through curing, as with hay, it is not used extensively in the United States because more labor is required than if the crop is pastured. Harvesting must be done every day, as the cut crop heats readily, and this chore is inconvenient, especially when other farm work is pressing.

The practice of using soiling crops throughout the entire growing season has been tried and almost invariably abandoned. In the first place it is impossible to arrange a succession of crops so that there will always be enough feed and not too much. Since it is necessary at times to resort to hay or silage feeding, and since a crop can be made into hay or silage more conveniently than it can be cut and fed green, there seems to be little advantage in using soiling crops as a regular summer feed.

Soiling as a supplement to permanent pastures is more practicable and is being used in certain sections of the United States. The crops used for this purpose are usually rye, vetch, Sudan grass, millet, soybeans, alfalfa, corn, sorghum, or some mixture of these. When the supply of permanent pasturage becomes inadequate some of these crops are cut daily and fed.

Dairy farmers appear to be the only ones who use soiling crops. A more usual practice even among dairy farmers is to graze such crops rather than to harvest them and feed them green.

HAY

FIELD CURING HAY

Most of the harvested forage is made into hay instead of being fed green or made into silage. The yield is greater in the form of hay than in the form of pasturage, because frequent harvesting as in grazing reduces the total yield. On the other hand the crop for hay is more mature and the nutrients are less valuable and less digestible. It has been estimated that the digestible nutrients obtained from the crop by grazing are about three-fourths as much as those obtained by making it into hay. No doubt this estimate is subject to change depending upon the energy that must be expended by the animals in the act of grazing. For example, if the grass is short or sparse, the energy expended in grazing is greater than if the grass is abundant. It is probable, therefore, that a smaller proportion of the nutrients ingested would be available for productive purposes when the grass is short.

Nearly all the hay produced in the United States is field-cured. Only a small proportion is artificially dried. The aim of the haymaker is to dry the crop with as little loss of leaves, color, and nutrients as possible. Loss of leaves is much more pronounced with the legumes than with the grasses. When legumes reach a certain stage of dryness the leaves shatter readily. In the case of alfalfa, Zink (*1277*) estimates this stage to be when the moisture content is 30 percent or less. This means that the necessary handling should take place as much as possible before the leaves are dry enough to shatter, and that any handling after that should be done in such a way as to reduce the shattering to a minimum or to save the shattered leaves.

If hay can be cut in the morning after the dew is off and can be dried enough for storage the same day, the field loss of nutrients will be quite low except for those mentioned. Any of the hay that is exposed to rain or dew and thereafter to the sun will become discolored rapidly. There is some bleaching even in the absence of rain or dew. For this reason hay should not, as a rule, lie in the swath overnight if it is dry enough so that it will finish curing in the windrow. It sometimes happens, however, when the crop is heavy, the ground moist, sunshine lacking or the weather cool, that the hay will not dry out enough so that it can be raked into a windrow the same day it is mowed. Legumes should be raked before the leaves become dry enough to shatter. This will be some time before the hay is dry enough to store. The grasses may be left in the swath until they are dry enough to store, except that they should not be left there overnight unnecessarily. Even with the grasses it is better to finish the curing in the windrow in order to save more of the green color.

An implement that crushes the coarse, slow-drying stems at the time of mowing and by so doing facilitates the escape of moisture from them has been found to speed up materially the process of drying. The conditions under which the use of such an implement is economical remain to be determined.

The side-delivery rake (fig. 2) is superior to the dump rake in that it leaves the hay in a loosely packed windrow conducive to continued rapid drying and suitable for taking up with a hay loader. The side-delivery rake is more expensive, however, rakes no faster, and requires two horses instead of one. The one time when the dump rake is just as desirable an implement to use is when the hay is to be put in the cock immediately or very soon. It packs the hay in the windrow and there is always some hay next to the windrows that is not raked.

The hay is usually stored direct from the windrow. In case of rain the windrows are scattered or merely turned to facilitate drying. If the prospects are for a number of rains before the hay can be stored, it would lessen the loss of nutrients and color to put the hay in cocks that would shed most of the rain. As a rule farmers prefer to handle the hay in windrows rather than cocks because cocking means extra labor and precludes the use of the hay loader. If loading is to be done by hand, cocking does not greatly increase the labor cost because the hay must be gathered together for pitching onto the truck or wagon anyway.

In regions where the common practice is to store hay in stacks instead of in barns, the hay is usually taken from the windrow with a buck rake and drawn to the stack, onto which it is elevated with a stacker. This is the easiest and most rapid method of storage known.

The windrow baler is being used successfully to a limited extent (fig. 3). Unless the hay is well cured the bales not only must be tied loosely but when stored must have enough space between them for

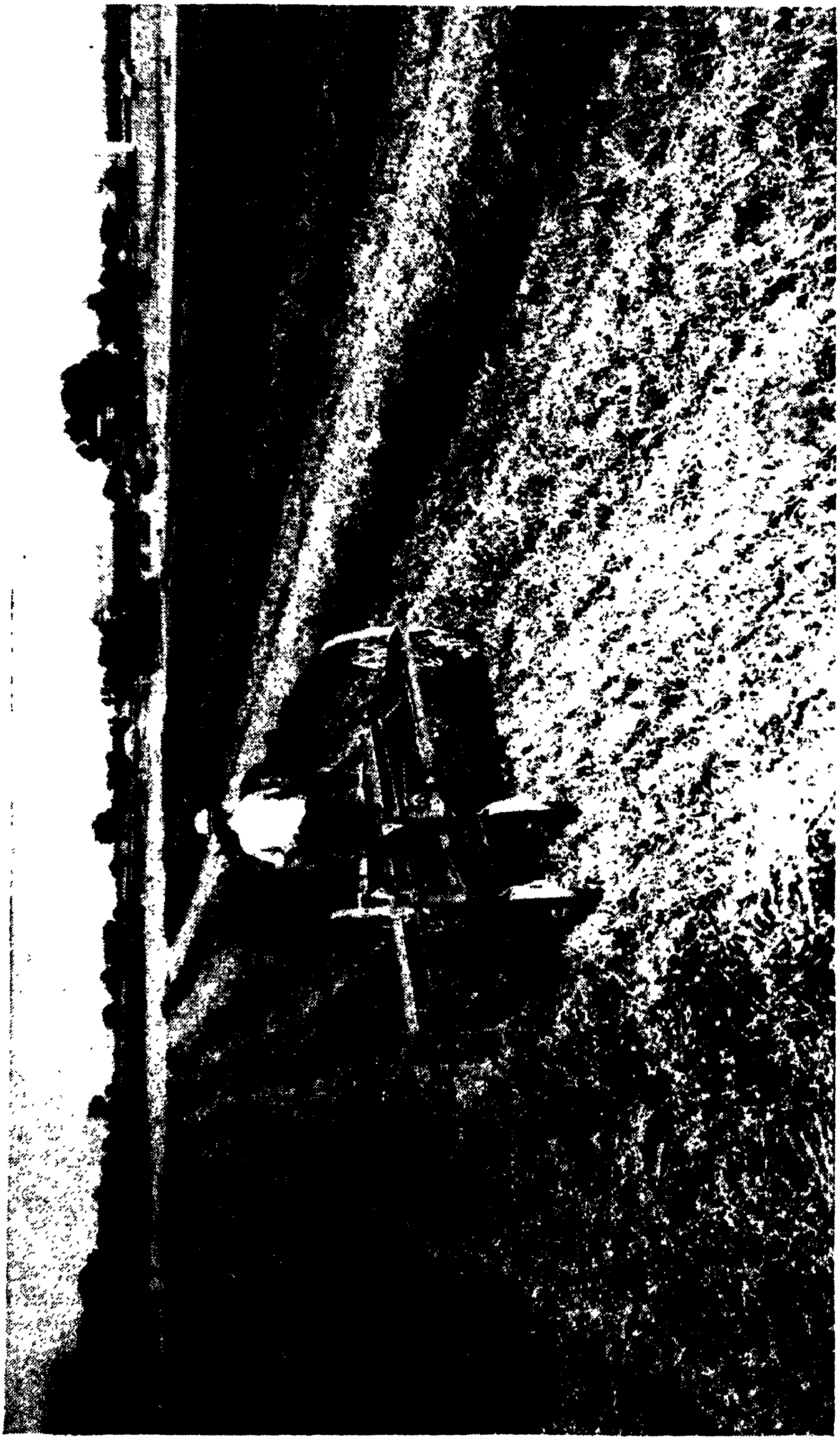

Figure 2.—The side-delivery rake leaves the hay in condition for continued rapid drying.

aeration, which will facilitate the evaporation of moisture and the radiation of heat. Baling from the windrow is advantageous in that less shattering occurs and storage space is reduced. Also, if the hay must be shifted from one place to another before feeding, bales are much more readily handled than long hay. Twenty percent of moisture appears to be about the maximum amount that hay can contain without some special attention to aeration. The more moisture the hay contains the greater the necessity for aeration to prevent the development of excessive heat, the loss of color, and the formation of mold. Baled hay containing as much as 30 percent of moisture is likely to spoil regardless of aeration.

In the drier regions of the West, alfalfa hay has been stacked[4] with over 30 percent of moisture and has come out of the stack with a good green color. Evidently the dryness of the atmosphere, the free exposure of the stack to the air, and possibly heavy stems that prevented close packing were factors that led to rapid drying of this hay in the stack. In humid regions if a considerable quantity of hay with more than 25 percent of moisture is stored in a poorly ventilated mow, it will become discolored and possibly musty. The grasses usually have a lower content of moisture than the legumes when they are put in the mow. The stems are not so heavy and they dry out more quickly. Furthermore, as leaf shattering is not serious with the grass hays, they can be allowed to become well dried before storing.

Field-cured hay is sometimes run through a cutter before storing. This saves half or more of the space needed for storage, depending on the length into which the hay is chopped. The finer the chopping the less space is occupied. Care should be taken not to overload the mow. Investigations by the Bureau of Dairy Industry (*1038*, *1266*) have shown that chopped hay becomes hotter in the mow and dries out less readily than unchopped hay with the same amount of moisture. The color is less well preserved in chopped hay. The length of cut is important. If the hay to be stored contains about 25 percent of moisture, which is perhaps not much more than alfalfa, clover, or soybean hay usually has at the time of storage, it must be chopped in lengths not less than three-fourths of an inch and too much must not be put in a pile. Even then the color and content of carotene will not be so well maintained as in similar hay stored unchopped, but so long as the hay is only slightly browned there will be no appreciable injury to the palatability as judged by the quantity consumed nor to the feeding value except with respect to the carotene. However, if the hay becomes very brown or black the palatability and feeding value are impaired. Any hay that has lost all of its green color contains little or no carotene.

It is advised that no hay containing more than 25 percent of moisture be chopped, and that any that is chopped be cut into lengths not less than three-fourths of an inch. More moisture or shorter cutting not only lessens the nutritive value of the hay but it may present a definite fire hazard. As there is no satisfactory method by which the farmer can determine the moisture content of the hay, he will have to be guided by his judgment of its dryness in the same way as when he stores hay in the unchopped form. He should bear in

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[4] For reference, see footnote 3, p. 968.

Figure 3.—Baling direct from the windrow is successful if the hay is not too moist and the bales are not too tight.

mind that drying should continue in the field until the hay appears as dry as or drier than is required to prevent excessive heating and discoloration if stored unchopped.

Chopped hay is more easily removed from the mow for feeding than unchopped hay, and because the stems are chopped up with the leaves the opportunity for selection by the animals of the choicer parts and refusal of the less choice is lessened. There is some difference of opinion whether it would pay to chop hay merely to secure more complete consumption, as the portions usually refused are those with a low nutritive value. Hay can be run through a chopper rapidly and it is unnecessary to have anyone in the mow to distribute it. This saves much hot work. It can be chopped and stored as rapidly as and with no more labor than unchopped hay can be stored with a hay fork and horse, but not as rapidly or with as little labor as when slings are used on the unchopped load and a mechanical hoist lifts the hay into the mow.

GRADES OF HAY AND THEIR RELATION TO THE NUTRITIVE VALUE

There is probably more variation in the quality of the hay crop as produced in the United States than in that of any other harvested feed crop. Although hay is ordinarily the basic feed around which all winter rations for horses, cattle, sheep, and goats are built, except in portions of the South and Southwest, feeders often have difficulty in utilizing it to the best advantage because of its poor quality. When animals are fed good-quality hay they consume relatively large amounts and obtain a maximum amount of nutrients from the hay portion of their ration. Poor-quality hay is consumed in limited quantities, so that it supplies only a relatively small portion of the total nutrients required and must be supplemented with more costly grain and concentrate feeds.

Quality in hay really means feed value. High-quality hay has certain physical and chemical characteristics that are associated with a high degree of palatability, a liberal supply of essential feed constituents, and a high digestibility. The important physical factors of quality which can be readily gaged in a practical way are: (1) Color, (2) leafiness in legumes, (3) maturity of plants when cut, (4) amount of foreign material, (5) condition, and (6) texture.

Under most conditions the physical factors mentioned above are correlated with the palatability and the chemical composition so that the quality or grade of the hay, as judged by its green color, leafiness, maturity, and other physical factors, is a good indication of its feeding value. Exact quantitative determinations of the relations of quality and feeding value in hay can only be made by feeding experiments in which the quality of the hay and the feeding value are measured by growth, gains in weight, reproductive ability, and the production of meat, milk, and other animal products. Little of such work has been done.

(1) For many years farmers and livestock feeders, as a result of practical feeding experience, have recognized the value of green color in hay. Even before it was found that vitamin A was associated with the green color and was essential to the health of the animal, color was

used as a quality factor in judging the value of hay. In establishing standards for hay, color was considered so important that studies were carried on for the purpose of developing methods of measuring it. It was found that the color could be measured in terms of hue, brilliance, and chroma with an instrument using color cards of standard values. The hue value was found to be the only reading needed, and conversion charts for converting the hue reading to percentage of green color were developed (fig. 4). A high percentage of natural green color in hay usually indicates early cutting, good curing, pleasant aroma, palatability, freedom from must or mold, and a relatively high carotene content.

The discoloration due to sun bleach does not reduce the amount of green as rapidly as discoloration due to rain, because the sun-bleach discolorations are yellow or yellowish green and represent only a partial destruction of the chlorophyll. Early-cut hay can receive a moderate amount of sun bleach before the green color is reduced below that required for the U. S. No. 1 grade, and rather severe sun bleach often will not reduce it below that required for the U. S. No. 2 grade. On the other hand, damage from showers and dews reduces the green color very rapidly, and the brown discolorations caused by this type of damage lower the grade materially. Only light showers or one or two heavy dews are needed to reduce the green color below that required for U. S. No. 1 grade; and if the weather damage is moderate to severe, the hay will not have sufficient color for the U. S. No. 2 grade. Severely weathered hay always falls into U. S. No. 3 or U. S. Sample grade.

Color is also lost after the hay is put in the mow or stack. Conditions in storage that accentuate the loss of color are high moisture content, tight packing, and poor ventilation. Hay is rarely so dry that it can be stored without the loss of some of its color, and under some conditions it may lose all of its green color. Only minute quantities of carotene are found in hays that have become brown or black in storage.

(2) Leafiness is not used as a grading factor in the grass hays. Very little data on the chemical analysis of the different parts of grass plants are available, and therefore no attempt has been made to use leafiness as a grading factor for these kinds of hays. It is true, however, that early-cut hays have more leaf than late-cut hays. Therefore, leafiness does follow the grade to some extent because those that grade best based on stage of growth at time of harvest also have the highest content of leaves.

The leafiness of legumes is probably the best gage of the actual feed value for this type of hay and therefore is an important physical factor in determining the grade of the hay. Alfalfa leaves contain on the average 24 percent of crude protein and 14.4 of crude fiber, while the stems contain on the average only 10.8 of crude protein and 38.3 percent of crude fiber. In other words, the leaves of alfalfa have on the average over twice as much protein as the stems. The protein in the leaves is also probably more digestible than that in the stems. Analyses of the protein in the leaves and stems of several of the other common legume hays indicate that they are very similar to alfalfa in this respect, although such data are rather meager.

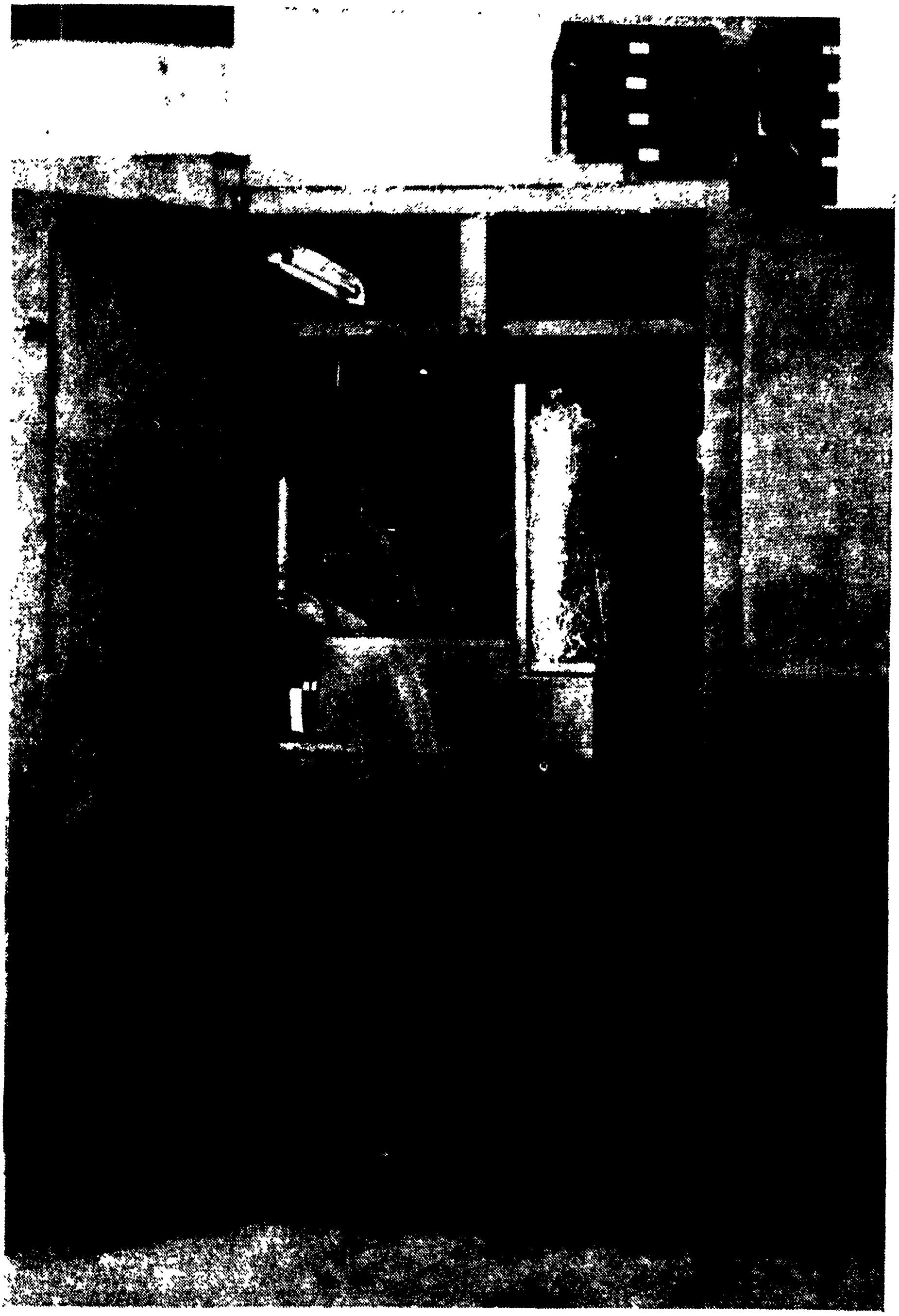

Figure 4.—Colorimeter set-up for measuring hay samples. An area 12 inches in diameter is measured. The observer looks through the eyepiece and sees a circular field. The top half is made up of the color of the hay, the bottom half of standard Munsell disk colors. The disk colors are mixed by means of a spinning wedge, and the color of the hay and disks are matched by changing the area of the disks.

Leafiness is also related to the mineral content of the legumes, and the leaves contain more calcium and phosphorus than the stems. The leaves of alfalfa hay are an excellent source of vitamin A, provided they are not discolored during the curing period, while the stems are a relatively poor source of this vitamin.

The percentage of leaves in legume hays will be affected by the methods of curing and handling. Ordinarily alfalfa will have 50 to 60 percent of leaves by weight when cut, if it is cut at the proper stage of maturity. Analyses of hundreds of samples taken from commercial lots of alfalfa hay show that on the average such hay has 39 percent of leaves; in some cases the percentage of leaves was as low as 15. These figures indicate that considerable leaf is lost during the curing and subsequent handling.

(3) The stage of maturity at which grasses and legumes are cut for hay influences the quality by affecting the color, leafiness, and other quality factors. The quality of many excellent crops of grasses and legumes is virtually sacrificed because they are not cut early enough. It is impossible to produce high-quality hay from late-cut grass and legume crops. The cell walls of young hay plants consist largely of cellulose, but as the plants mature the lignin increases at a more rapid rate than the cellulose.

(4) Foreign material, as defined under United States hay standards, includes materials that are wasted in feeding operations. Noninjurious foreign material includes weeds, grain straw, stubble, chaff, and other material not suitable for feeding purposes but occurring naturally in hay. Injurious foreign material includes sand burs, poisonous plants, harsh bearded grasses, and other matter which is injurious when fed to livestock. Foreign material is used as a grading factor, the grade being lowered in proportion to the amount present if the hay contains over a certain percentage of foreign material. The quantity permitted varies, depending on the type or class of hay. Foreign material gives the hay a bad appearance, and often undesirable weeds are spread because of the weed seeds in such hay.

(5) Condition in hay refers to soundness or unsoundness. Since the factors of quality in sound hay have been discussed above, the discussion here will be confined to the condition of unsound hay. Undercured, heating, and hot hay is hay containing excessive moisture and therefore is considered "out of condition." Must is the sour fetid odor which occurs in hay that has heated, while mold is the fungus plant organism that grows on the hay when moisture and temperature conditions are favorable. Moldy hay is generally not as palatable as hay that is free of mold, and it may be harmful to certain classes of livestock. Molds present in sufficient quantity to be seen indicate that there has been a reduction in the feed value of the hay caused by the mold or other micro-organisms.

Aroma in hay is rather elusive, yet any early-cut, properly cured hay has an odor that livestock relish and which probably affects its palatability. Hay with a musty or earthy odor, indicating poor curing or damage after storing, may not be relished by livestock.

(6) Texture or size of stems in the various hay plants is dependent to a great extent on thickness of stand and on maturity at cutting time. Ordinarily it is not a factor in the grass hays such as timothy,

red top, etc., but it is important with Johnson grass and other grasses of the sorghum group. Soybean hay also has a tendency to be coarse in texture, especially when grown from the seed types. This objection is overcome to a large extent by heavy rates of seeding. Occasionally, lots of alfalfa are found with undesirable texture because of having been grown on very fertile land or because, owing to late cutting and dry weather, the stems are very hard and brittle although of small diameter. Such hays are relatively unpalatable even though the color and leafiness may be satisfactory.

ARTIFICIALLY DRIED HAY

The nutrients of hay are perhaps better preserved by artificially drying it than by any other method of curing. There will be some unavoidable loss of carotene and of the more volatile nitrogen compounds in the process of drying, but in other respects the nutrients in the dried hay should be equal to those in the fresh green material. In the United States artificial drying has been confined mostly to two sorts of enterprises: (1) Farms where a specialty is made of a particularly high-class product, and something in the nature of the feed or the handling of the product must be better than on most other farms in order to justify an extra price for the product; (2) plants or farms where hay, usually alfalfa, is dried and ground for use in feeds for poultry and to a lesser extent for other kinds of farm animals. The costs of the drier and of operation have been high enough to preclude its profitable use by the average farmer. The cost of drying, the climate, and the value of the artificially dried hay as compared with naturally dried hay are factors to be considered in determining whether artificial drying is likely to be practicable.

The studies that have been made are not sufficient to fix definitely the cost of drying. The type of drier, the fuel used, the moisture content of the crop, the kind of crop, the length of the season during which material is available for drying, and whether or not the material is chopped or crushed before drying all have a bearing on the cost. From data assembled by Gordon and Hurst (*426*) it is estimated that when the moisture content of the crop is 60 percent, about 30 gallons of fuel oil are required for a ton of dried hay like alfalfa or soybean if the crop is chopped and drying is done in an efficient type of drier. The cost of this oil may range from 3 or 4 to 7 or more cents a gallon. To this cost must be added that for power, labor, depreciation, repairs, interest, taxes, and insurance. Gordon and Hurst estimate the power, labor, and fuel costs at $1.69 to $3.07 per 1,000 pounds of water evaporated. Assuming that 2,500 pounds of water is evaporated for each ton of dried hay, the minimum cost will be $4.22 per ton of dried hay, exclusive of overhead charges. The overhead charges depend mostly on how much use is made of the drier. They are not likely to be less than $1 per ton of dried hay and they may be several times as much. It appears, therefore, that hay which is no more than well wilted in the field cannot be dried for less than $5 per ton of dry material, and the costs are likely to run much more than this. If a considerable part of the drying takes place in the field the fuel and labor for finishing the drying artificially will be much less than if the crop is freshly mown or only wilted. Such a practice, however, would defeat some of the objects of artificial drying, namely, the preservation of a maximum amount of carotene and the elimination of the weather hazard.

The next consideration is how much artificial drying increases the feeding value over that of sun-cured hay. No feeding experiments of sufficient length have been conducted to show how dehydrated and field-cured hay compare. Probably there is no marked difference if the hay cured in the field is of good quality except in those cases where carotene is the limiting constituent. The digestible nutrients as determined by Newlander and associates (*851*) offer the best available basis for estimating the relative nutritive values of sun-cured and dehydrated hay. The total digestible nutrients of the sun-cured hays was 60.47 percent; of dehydrated hay, 63.76 percent, a 5-percent increase over the sun-cured. There is no doubt that artificial drying, when properly done, makes a hay that is superior to field-cured hay in color and content of carotene, nor is there any doubt that artificial drying usually lessens the field losses due to leaf shattering and weather damage. If the losses in field curing are, say, 25 percent, then for a ton of artificially dried hay an equivalent yield of field-cured hay would be 1,500 pounds. Will the value of 500 pounds of hay equal the cost of artificially drying 1 ton? Ordinarily it will not, but if the field losses are greater than 25 percent, which may very well happen with certain crops and weather conditions, and if at the same time the prices of hay are relatively high, then artificial drying may pay. However, unfavorable weather conditions rarely occur for a whole haymaking season, and if the drier is used only when good hay cannot be made in the field, the overhead expense becomes excessive. It is probable that the use of artificial drying will develop slowly in the United States, partly because there is not the demand for it that there is in cooler and cloudier countries and partly because the silo offers another alternative in preventing weather damage to forage crops. Furthermore, artificially dried hay does not compete with sun-cured hay in commercial channels, as most of it is chopped before being dried and therefore it is not baled.

HAY MEALS AND LEAF MEALS

The principal object in grinding hays is to facilitate their mixing with other ingredients in making commercial mixed feeds. Well-cured hays provide some of the vitamins and minerals likely to be lacking in mixtures made up of seeds and their byproducts. Alfalfa is by far the most important hay used for grinding. As grinding masks to some extent the quality of hay, it has been much used in the past as a means of working off stemmy, weedy, and unsound hay. So far as the nutritive value of the hay is concerned there is no evidence that grinding improves the palatability or digestibility. Theoretically it should reduce the labor of mastication and for that reason alone show a greater value than unground hay. Experiments show, however, that there is practically no difference between ground and unground roughages in feeding value.

Roughages are often chopped or ground not only to save storage space, as discussed earlier in this article, but also to induce consumption of those parts of the roughage that in the unground state would be refused and wasted. Grinding, of course, serves the same purpose but chopping is much cheaper than grinding.

About 400,000 tons of alfalfa hay was ground in the crop year 1938 for use in the commercial mixed feeds. Most of this hay is ground by a small group of concerns which specialize in the production of alfalfa products—alfalfa meal, alfalfa-leaf meal, and alfalfa-stem meal. These products are used principally by the mixed-feed manufacturers. The alfalfa-leaf meals are used in poultry and hog feeds, the alfalfa meals in poultry, hog, and dairy-cattle feeds, and the stem meals in molasses feeds for horses and mules.

The leaf meal is superior to that made from the whole plant in carotene and protein content. It also contains less fiber. Perhaps the principal reasons for using leaf meal for poultry and hogs are its high content of carotene and the fact that the digestive systems of these animals are not adapted to the efficient utilization of crude fiber.

The feed-control officials of the various States have certain fiber requirements for the different types of meal and a few have protein requirements.

Alfalfa-leaf meal is produced by grinding alfalfa hay and then removing the leafy particles by sifting the ground material. The leaves pulverize more readily than the stems and can be separated from the stem particles by a proper sifting device. The residue left after removing the leaf meal is called stem meal. A number of the manufacturers produce a special alfalfa meal, which is a product from which a part of the stem particles have been removed but which does not meet the requirements for leaf meal. This type of meal is usually sold under a trade name.

As stated in the section on artificially dried hay, much of this dried hay is ground into meal. About one-fourth of the total production of ground alfalfa is dehydrated meal at the present time.

SILAGE

Silage is a moist feed that has been preserved in the absence of air. The principal silage crop is corn. In those parts of the country where sorgos yield considerably more than corn they are used in preference to corn. Also in those parts of the country where neither corn nor the sorgos do well, other crops such as oats, peas, and sunflowers are used to some extent. In recent years there has been a movement toward the preservation of grass and legume crops in the silo. Silage is not a necessary part of the ration for any kind of livestock. The succulence formerly thought to be important in rations has been shown to be unnecessary.

The silo is useful in preserving the corn or sorgo in such a way that the greatest quantity of nutrients will be conserved. It is also useful in preserving crops that might be badly damaged or lost if an attempt were made to make them into hay. Silage appears better adapted to ruminants, especially cattle, than to other classes of livestock. For these reasons silos are more numerous on cattle farms and in those sections of the country where corn and the sorgos do well and the making of a good quality of hay is uncertain. Furthermore, as dairy cows cannot be roughed through the winter like beef cows and still give profitable quantities of milk, the silo is particularly adapted to dairy farms in that it provides an abundance of palatable feed that can be fed conveniently to cows confined in a barn. An outstanding characteristic of silage is its high content of carotene if it is properly made from green crops. This also makes it particularly popular on dairy farms because of the need of the cows for carotene and vitamin A to be secreted in the milk.

The unavoidable losses of dry matter in silage made in a good silo should ordinarily not exceed 10 percent. The spoilage on top and around the sides near the top is greater with the hay crops than with corn. Suitable means for preventing this undue spoilage of the hay crops have not been worked out. There should be no more total loss of nutritive value in making silage than in making hay under conditions favorable for haymaking, and considerably less loss under conditions that are unfavorable for hay.

SOME CHANGES THAT TAKE PLACE IN SILAGE

When a fresh green crop is put in the silo a number of changes take place. Peterson and associates (*918*) have shown that green crops continue respiration and by so doing use the oxygen in the interstices of the silage and replace it with carbon dioxide. In a few hours the oxygen is exhausted and the gases within the silo are nearly all carbon dioxide and nitrogen. Coincidently the temperature rises and bacteria multiply rapidly.

The temperatures attained depend on the quantity of air present, which in turn depends on the fineness of chopping, the firmness of packing, and the imperviousness to air of the silo walls and doors. Furthermore the temperature of the crop when put in the silo and the outside air temperature have an influence on the maximum temperatures attained. Silage as it is usually made in the United States generally does not reach a temperature above 100° F., except near the surface where the material is not packed tightly and where there is also some infiltration of air. The maximum temperature is reached in a few days, after which it slowly subsides. Hunter (*563*) states that silage temperatures are due to microbial activity and not to intramolecular respiration of plant tissue.

The principal food of the bacteria appears to be the sugars, pentosans, and starches (*918*). Although some of the proteins are reduced to simpler compounds, the end products in the fermentation of carbohydrates are acids—mainly lactic and acetic. The lactic fermentation is the one most desired. Wilson and Webb (*1236*) found that crops like corn, the sorgos, and small cereal grains have a high content of easily fermentable carbohydrates. As these crops also have a low content of calcium and other basic elements, the acidity soon develops to a point indicated by a pH value of about 4 or below. Other crops, like the grasses, may have less of the soluble carbohydrates and more of the basic elements, and for these reasons develop less acid. The legumes contain still less of the soluble carbohydrates, which with the high calcium content keeps the acidity low. These are the reasons for adding acids or fermentable carbohydrates to certain crops at the time they are put in the silo.

Peterson and associates (*918*), working with corn silage, have shown that the numbers of bacteria, chiefly lactic acid producers, may reach

1 billion or more per cubic centimeter of juice in a few days. Thereafter the numbers diminish, and the low-acid types of bacteria (*Bacillus lactic acidi*) are replaced by types which both tolerate and produce more acid (*Lactobacillus pentoaceticus*).

Swanson and Tague (*1113*) stated that a portion of the protein is converted into the amino form and also that low acidities favor such conversion. Peterson and associates (*915*) made alfalfa silage with and without the addition of mineral acids. The addition of acids reduced the content of water-soluble, amino, and ammonia nitrogen.

FACTORS AFFECTING THE QUALITY OF SILAGE

Acidity

Corn, sorgo, and certain other silages have a sour taste due to the development of lactic and acetic acids. Because silages are sour, it has commonly been assumed that considerable acidity is a prerequisite to preservation. Recent work by the Bureau of Dairy Industry (*1267*) has shown that silages can be preserved effectively with the development of only slight amounts of acid and at the same time be palatable and possess a high nutritive value. The quantity of acid produced is said to depend on the amount of water-soluble carbohydrates in the plants, and it is known that young plants have less of these than older plants. If the quantity of acid developed depends solely on the content of soluble carbohydrates, then immature plants should make silages with less acid than mature plants. Investigations and practical experience both show that the reverse is true, at least with corn and the sorgos. Furthermore, it has been stated that either acids or carbohydrates from which acids can be made must be added to crops deficient in soluble carbohydrates if such crops are to be siloed successfully. It appears that there are factors other than the content of soluble carbohydrates that have a bearing on the quantity of acid developed in the silo.

Acids unquestionably influence the character of the fermentation, but they are not necessary to prevent molding or rotting of the silage. Corn silage of rather high acidity (pH value below 4) will mold as readily when exposed to the air as will the fresh, green corn. The only condition required to prevent molding or rotting is the quick expulsion or exhaustion of air from the silo and the exclusion of air thereafter. This in itself does not, however, insure an acceptable silage with some of the hay crops. Undesirable fermentations may take place if the silage is very moist and the acidity at the same time is low. These fermentations are characterized by offensive odors that are generally attributed to the formation of butyric acid, and they may be prevented by adding acid.

An important method of making silage, called A. I. V. (from the initials of its principal sponsor, A. I. Virtanen), is based upon the employment of acids to prevent undesirable fermentations. While the addition of acids does prevent protein break-down and the development of offensive odors and lessens the losses of dry matter, certain disadvantages of this method have come to light. The acid is destructive to any masonry or concrete construction, it is troublesome to apply, it must be neutralized when the silage is fed, and it adds no nutritive value; but the principal disadvantage is that it seriously impairs the palatability of the silage. It was formerly thought that the acid was unusually effective in preserving the carotene. Recent work by the Bureau of Dairy Industry (*1244*) has shown that much of the material that has passed for carotene by the usual method of determining it is in reality not true carotene.

It is difficult to reconcile the undoubtedly good results from the acid treatment of silage in the north-European countries with the mediocre results of such treatment in this country. Possibly differences in the methods employed will account in some measure for this lack of harmony. In Europe where the acid treatment is used, the usual type of silo is a pit in the ground 6 or 7 feet deep around which is built a temporary wooden superstructure 6 or 7 feet high. The silo is filled with fresh, unchopped grass on which is sprinkled the dilute acid as the filling proceeds. When the silo is full a foot or so of dirt is thrown on top. In the course of a week or so the silage settles to about the surface of the ground. The wooden superstructure is then removed. Much more air is trapped in the silo by this method than by American methods, by which the crop is almost invariably chopped before it is put in the silo.

One of the conditions given for the successful use of the A. I. V. method is that the acidity be high—represented by a pH value below 4. A great many specimens of excellent silage made from hay crops have shown a pH value above 4, in fact most grasses and legumes made into silage without the addition of acid have a pH value well above 4. It is possible, therefore, that much less acid than recommended may be enough to make a silage that smells good and at the same time is more palatable. No evidence of a conclusive nature has been presented to show any necessity of reducing the pH value below a point which will prevent the butyric acid fermentation. An acidity represented by pH 4.4 or even higher is said to be enough to prevent the formation of this acid. It is possible, therefore, that some modification of the A. I. V. method might prove practicable in the United States.

Molasses is sometimes added when silage is made from the hay crops in order to furnish the carbohydrates from which acids may be formed. Swanson and Tague (*1113*) found that all the sugar disappeared, even when added at the approximate rate of 5 percent. A considerable number of investigations show that the addition of molasses results in a greater acidity of the silage, but the quantity of acid developed fails to account for all of the sugar added in the molasses. In other words, a considerable part of the sugars in the molasses is changed to some compounds other than acids. Virtanen and Karström (*1170*) have presented evidence that sugars lower the pH value and increase the lactic acid only slightly. Increases in ethanol following increases in sugar indicate that a considerable part of the sugar disappears through alcoholic fermentation.

While molasses increases the acidity only slightly—with the grasses and legumes rarely to a point below pH 4—it does improve the quality of high-moisture silages made from the hay crops by improving the odor and by making it more palatable.

Temperature

The temperatures of silage depend to a large extent on the quantity of air present in the silage. Dr. Gorini of Italy, in an unpublished report, has described a method of silage making which depends for its efficacy on the development of the proper amount of heat to discourage the bacteria producing butyric acid without killing those that produce lactic acid. Briefly, the method is to ensile the fresh young grass in layers 2 or 3 feet deep, always allowing each layer to heat to a temperature of 140° F. before the next layer is placed on top of it. Preliminary investigations of this method in the United States indicate that the silage produced is palatable and has a good odor but that the carotene content is much reduced. The principle of this method is employed in making stack silage in New Zealand and perhaps also in other countries.

Moisture

It has commonly been assumed that silage must have a high content of water in order to keep properly. Samarani (*1002*), Eckles (*293*), and Swanson and Tague (*1113*) showed many years ago that silage made from the hay crops was improved by reducing the moisture content of the crop before it was ensiled. More recent work by the Bureau of Dairy Industry (*1039*, *1267*) and by Perkins and associates (*909*) bears out the findings of the earlier investigators. Low-moisture silage undergoes less fermentation and a more desirable type of fermentation than high-moisture silage, as evidenced by the lower losses of dry matter, the more agreeable odor, and the greater palatability. No silage possesses a more objectionable odor than that which is so full of water as to be waterlogged. Very high moisture contents increase the labor of filling the silo, and the leakage of juice from the silo may be a nuisance. A moisture content of 70 percent or less in the crop will obviate leaking. By exercising proper precautions in regard to the exhaustion and exclusion of the air, crops with any moisture content ranging from 70 percent down to 10 can be preserved successfully in the silo. However, because of the practical difficulties in excluding the air from very low-moisture silages and the necessity for using silos with airtight walls and doors, the advice at present is to refrain from drying crops to a moisture content of less than 50 percent, although investigations by the Bureau of Dairy Industry (*1039*) show that material drier than this can be preserved in the silo with little loss of nutrients and in a form that is quite palatable and nutritious. The disadvantages of partial drying are that some of the carotene is lost in the interval between mowing and chopping and that the partially dried material packs less compactly than the moister material, thus increasing the difficulty of excluding the air.

Any kind of silo that excludes the air and prevents the access of surface or seepage water will preserve silage effectively. This may be an ordinary upright or tower silo built of wood, brick, tile, stone, metal, or concrete; or it may be a pit, a trench, or a more temporary structure, such as paper-lined snow fence. If the silo is to be used for the hay crops it is much more important that the walls and doors should be airtight and that the walls be smooth than if it is to be used

Figure 5.—Any of the crops ordinarily used for hay can be made into good silage.

for corn or the sorgos. So long as the essential conditions are met, the silage from one type of silo is equal to that from any other type.

Ordinarily the best stage of maturity at which to harvest corn for the silo is when over half the kernels have hardened so that no more milk is present, but before they have all hardened. If harvested before this stage the yield of dry matter is reduced and the silage is likely to have an excessive acidity. On the other hand the content of carotene is greatest when the crop is greenest. Under some conditions, when carotene is likely to be deficient in the ration, as may very well happen with high-producing dairy cows fed a discolored hay, it is desirable to harvest the corn at a time when the carotene content is more nearly at its maximum. Harvesting later, say at the stage usually thought best for shocking, is advantageous in that a greater yield of dry matter will be obtained, but it is disadvantageous in that the drier silage will not have so much carotene, will not pack so well in the silo, and may not be so palatable

On some farms filling the silos may take 2 weeks or more. In that case it would be better to start filling in time so that at the finish the maturity of the corn will not be much beyond the optimum stage. When drought occurs the crop should be put in the silo before it fires too badly, regardless of the stage of maturity of the grain. The crops should be chopped fine, in order to make them pack more closely in the silo and thus force out the air. There is no apparent advantage in adding acid, molasses, sugar, bacterial cultures, or any other substance to corn or the sorgos. Usually no trouble is experienced in making silage from these crops if the silo is reasonably tight and the material is moist enough to pack well.

The grasses or mixtures of grasses and legumes used for hay and small-grain crops can be siloed almost as readily as corn (fig. 5). The stage of maturity that is best for the making of hay is also best for the making of silage. Sometimes when the crop is immature and has a very high content of moisture or becomes waterlogged by external moisture, it develops bad odors. The legumes are more likely than the other crops to develop bad odors indicative of butyric acid formation and the break-down of the proteins into simpler nitrogen compounds. For this reason special precautions must be exercised when they are made into silage.

METHODS OF MAKING SILAGE

When no special treatment is accorded, the crop is merely harvested and chopped into the silo, usually with not more than a few hours elapsing between the time it is cut or mowed and the time it is run through the silage cutter. Such practice is successful in the making of silage from corn, the sorgos (including Sudan grass), and the small grains, and if the moisture content is below 70 percent it is successful in making silage from all other crops.

Addition of Acids

Hydrochloric and sulfuric acids are the acids most commonly added to the silage. They are diluted with about five volumes of water. The solution is then pumped into the silo and sprinkled over the chopped material as it enters the silo. The amount of the diluted acid to use to bring the pH value to a point below 4 is about 5 to 8 percent of the weight of the crop, depending upon the kind of crop. Grasses require the smaller amount and legumes the larger. When the silage is fed, some such material as finely ground limestone is sprinkled over it in order to neutralize the acidity. One ounce is used for approximately each 15 pounds of silage.

More recently liquid phosphoric acid has been used to a limited extent. The theory is that the phosphoric acid will serve three purposes—increase the acidity in the same way as hydrochloric and sulfuric acids, insure against any deficiency of phosphorus in the ration, and return any that is not used to the soil in the manure. The quantity advised is about 0.8 percent of the weight of the crop or 16 pounds (1¼ gallons) to the ton. With alfalfa this is not enough to reduce the pH value below 4. The silage produced has a good odor and is palatable, but there is as yet insufficient data to permit a statement with regard to the physiological effect upon the cows. Before using phosphoric acid one should be assured that the fluorine content is not great enough to cause injury when the silage is fed.

Addition of Molasses

In the United States molasses has been used to a slight extent ever since its possibilities for silage production were investigated by Reed and Fitch (*952*) in 1917, but in the last few years its use has increased enormously. Amounts are used varying from 1 percent to as much as 7 percent of the weight of the crop. It appears that commercial concerns have overemphasized the importance of molasses. In some cases excessive amounts are advised, and in others it is advised when the need for it is not indicated.

Molasses is added in a number of ways. It may be allowed to flow by gravity or by air pressure, undiluted, directly on the crop as it travels along the feed table of the cutter; it may be diluted and run into the blower of the cutter or pumped to the top of the silo; or it may be forced through an automatically regulating device attached to the silage cutter. A uniform distribution of the molasses is difficult by any of the methods now in use.

The costs of each of the acid treatments and of the molasses will be much the same unless very large quantities of molasses are used. The cost of the materials alone will usually be at least 60 cents per ton of silage. To this must be added the extra labor required to apply the acids or molasses.

High-Temperature Process

The high-temperature process has not come into use in the United States. One reason for this is that it does not fit in well with the methods ordinarily used here in making silage. The practice in the United States is to fill silos quickly—sometimes in a single day. The high-temperature process requires slow or intermittent filling in order to permit the temperature of successive layers of the silage to reach 140° F. or thereabouts. Probably this method can be applied more conveniently to trench silos than to the ordinary tower silos.

Partial Drying

High-moisture legumes and the young grasses if siloed without some special treatment are likely to make malodorous silages that may taint the milk and in which much of the protein has been converted into simpler and less valuable nitrogen compounds. Materials with more than 70 percent of moisture are likely to leak juice from the silo. This is not only objectionable for sanitary reasons but the loss of nutrients in the juice is considerable.

Crops cut at the usual haymaking stage will have about 75 percent of moisture. The moisture may be higher than this if the crop is immature or if the soil is moist, and it may be lower than this if the crop is mature or if it is harvested in dry weather. In order to prevent leaking, the high-moisture crops will often have to be wilted before they are put in the silo. The time required for sufficient wilting depends on the amount of moisture which must be evaporated and on the weather. It may be only an hour or so, or it may be a day or more.

The objections that have been raised to wilting or partial drying are: (1) Some of the carotene is lost during the wilting process; (2) there is no practicable way of telling when sufficient wilting has taken place; (3) it is more difficult to exclude air from the partly dried silage. In certain dairies featuring milk with a high vitamin A content the first objection may be important in spite of the fact that perhaps not over 20 percent of the carotene is lost during wilting and that there is still more than enough to maintain milk production and the health of the cattle. The second objection is of no great consequence because the range in moisture contents below 70 can be considerable without any particular disadvantage. The third objection can be overcome by topping out the silo with a load or two of high-moisture material. If the silage is very dry it cannot be depended on to tighten wooden silos by causing the staves to swell and close the cracks. The lower the moisture content of the crop, the greater is the necessity for tight walls and doors.

Wilting or partial drying compared with no treatment improves the palatability and odor of the silage and obviates leaking; compared with the addition of hydrochloric and sulfuric acids, it is easier and less expensive, the silage is more palatable, and leaking is obviated; and compared with the addition of molasses, it is easier and less expensive, the silage is fully as palatable, and the losses both from fermentation and leaking are likely to be less.

Chopping

All silages should be chopped finely rather than coarsely. This appears to be more important with crops having coarse stems or stalks like corn and with hay crops having a low moisture content than it is with high-moisture hay crops. Much of the coarser portions of corn cut in long lengths is likely to be refused by livestock; long-cut hay crops with a low moisture content may not pack closely enough to prevent spoilage. In any event fine cutting makes it possible to put a greater tonnage in a given space. There is some evidence that half-dried hay crops are more difficult to chop than crops that are either wetter or drier.

If there is a lapse in filling of more than 2 days, a layer at the top of the silage is likely to mold. This layer may be removed before filling is resumed, or it may be discarded when the silage is removed for feeding.

USE AND LIMITATIONS OF HAY AND SILAGE AS FEEDS

Silage is the dairy farmer's main reliance for winter feed in those regions of the United States where corn or the sorgos do well and hays are cured with difficulty. It not only provides nutrients at a nominal cost but also, because of its carotene content, provides for more perfect nutrition of livestock in regions where the hay is of poor quality. The nutrients in hay and silage are usually cheaper than those in grains. If good hays can be produced in abundance and cheaply, there is no particular need for silage. Good hays contain the elements for satisfactory nutrition and practically as much nutriment will be eaten in a ration of good hay alone as in a ration of good hay and silage. However, if the hay is not of good quality, more nutrients will be eaten in hay and silage fed together than in hay fed alone. Silage is also an excellent feed for beef cattle and sheep, but these classes of livestock are perhaps not so much in need of the carotene contained in silage as are dairy cattle.

Cattle will do well on a ration having corn silage as the sole roughage but not so well as if some hay is fed too. They will not consume as much nutriment without hay, and corn or sorgo silage is too low in proteins and minerals. Corn and sorgo silages are particularly well supplemented by legume hays. The best quantities to feed of silages made from the hay crops and the way in which they can best be supplemented have not been worked out satisfactorily. Those who have had experience in feeding high-moisture legume and grass silages advocate the feeding of some hay along with the silage. Probably the moisture content of the silage will have an important bearing on whether or not some hay is to be fed. Low-moisture silage (about 50 percent of water) was fed to dairy cows by the Bureau of Dairy Industry (*1039*) in comparison with a good-quality hay. The consumption of dry matter in the form of silage was fully equal to that in the form of hay, and the milk flow was as effectively maintained.

Any kind of nonlegume, whether used as hay or silage, has a content of protein too low for most feeding purposes unless harvested at an immature stage. Even then some nonlegumes contain too little protein for growing stock and milking animals. All forages, whether legume or nonlegume, fail to contain sufficient available energy for maximum production of meat or milk. In such cases supplementary feeding with more concentrated feeds is indicated. Usually, there is nothing about the process of making crops into hay or silage, if well done, that materially changes their palatability or nutritive value from what it was in the green state except that the hays sustain a heavy loss of carotene. For the maintenance and gestation of ruminants these feeds ordinarily contain enough available energy, but the protein may be deficient in the nonlegume hays, in the silages made from cereals, and in the silages made from grasses unless these are harvested at an immature stage.

The harvested forages not only provide the essential nutritive constituents that are contained in seeds and their byproducts but they also provide vitamins A, D, and G and most of the minerals in much greater quantities than do most of the concentrated feeds. If grown on soils that have no pronounced deficiencies and harvested and stored in a proper manner they will provide, so far as known, all or nearly all the essential nutritive constituents for livestock except common salt, and in some cases protein and possibly phosphorus. The digestive systems of poultry and swine are not adapted to the handling of large quantities of crude fiber such as are found in the harvested forages. For this reason forages are mainly used for these two classes of livestock to supplement more concentrated feed and to provide the nutritive constituents, vitamin A particularly, which may be lacking in the concentrated feed. Even the herbivora may at times need more energy than is contained in harvested forages; working horses and fattening stock are familiar examples, while lactating animals may require more protein and possibly more phosphorus as well as more energy. Concentrated feeds such as the cereals and byproducts of the oil mills, flour mills, meat-packing establishments, etc., are used to provide the protein and energy which may be lacking in the forages, and wheat bran, oil meals, or compounds of phosphorus, particularly bonemeal, are used to provide the phosphorus.

There are a number of important problems relating to hay and silage which remain to be solved. A few of them follow:

The influence of the grade of the hay on the palatability and nutritive value should be determined in order that relative monetary values of the different grades may be estimated.

The extent to which concentrates can be profitably replaced by forages is a matter of vital concern to all persons interested in the economical feeding of livestock and in the conservation and improvement of the soil.

The kind of bacteria that are responsible for malodorous silage and protein break-down and the conditions favoring their development should be determined in order that such conditions may be recognized and avoided.

The conditions required for the certain preservation in the silo of hays field-dried to a point approaching that at which they are usually stored in a stack or mow should be investigated. Storage of the hays in a silo instead of a mow would lessen the hazard of fire as well as preserve more of the feed nutrients.

The possibility of using cheap mineral acids in much smaller quantities than commonly advised should be studied. High acidity impairs the palatability and probably is not necessary for satisfactory preservation of the silage.

The influence of phosphoric acid on the quality and nutritive value of the silage should be investigated.

LOSSES IN MAKING HAY AND SILAGE

by J. A. LeClerc [1]

HERE is a thoroughgoing account of the losses that may be expected in hay and silage as compared with the fresh plant material. Under each heading the author first gives a general account, with recommendations. and follows this with a detailed summary of experimental data, including much technical material. He describes the newer methods of handling forage crops—including the use of cakes made of fresh grass—and the most important methods of preparing silage.

HAY

UNTIL a very few years ago field curing was practically the only method ever used in preparing hay for storage. Considering the fact that even with normal practice and under normal weather conditions, haymaking in many sections of this country is accompanied by a loss of dry matter amounting to 10 percent or more, it follows that the loss to farmers each year may amount to at least 75 million dollars. If the weather during haying is unfavorable, the loss in nutritive value may easily be several times as great as normally, entailing a correspondingly larger financial loss.

Studies of hay crops cured and stored by traditional methods as compared with newer methods appear to support the following conclusions:

1. Field curing of hay, under ordinary conditions, is always accompanied by appreciable mechanical losses of leaves—that portion of the crop richest in dry matter, protein, vitamins, and minerals.
2. Losses of valuable constituents of the hay as the result of rain may account at times in certain localities for as much as half the value of the crop (hence the old adage, "Make hay while the sun shines").
3. Losses by artificial drying are small compared to those by field curing.

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4. Artificial drying can be done in any weather. There is no loss from leaching, little loss of carotene, and little or no loss from shattering of leaves. The product is a better feed than is the ordinary field-cured product.

5. Since the leaves are the most nutritious portion of the crop, it is essential to cut the hay when the leaves are in greatest abundance. Artificial drying of hay is the surest way to save the greatest proportion of the leaves.

6. The utilization, by artificial drying, of young grass (before the nodes are formed) might prove of great monetary value to farmers, especially in certain sections of this country where weather conditions are favorable for the growth of grass, and where there is a lack of concentrated feeds.

7. The processing of young dried grass (before the stems are formed) into so-called grass cakes by compressing machines appears from English experiments to have promise. This process might prove worthy of study in certain sections of the United States.

8. Young-grass cakes appear to have unusual food value. A study of the chemistry and feeding value of young grass may reveal factors, now unknown, which have an important bearing on the health of animals and man.

9. The utilization of young grass appears to be a means of increasing the national wealth by assuring better health to animals through a supply of feed richer in essential minerals and vitamins than many of the feeds ordinarily used, and consequently producing more nutritious animal food for man. The conservation of young grass promises to play an important role in the agriculture of certain parts of this country.

DATA ON HAYMAKING AND ON NEWER METHODS

Losses in Field-Cured Hay

According to Fleischmann (*364*),[2] the field curing of hay is always accompanied by profound changes in the constituents, even though the losses may be slight, and hence it is not correct to refer to dried hay as "low-moisture green fodder."

The losses of total dry matter during haymaking may vary from 10 to 30 percent; of digestible dry matter, from 15 to 35 percent; and of starch equivalent (1 pound of starch equivalent has an average net energy value of 1.071 therms (*819*)) from 25 to 50 percent.

A picture of the losses in dry matter and protein is found in tables 1 and 2, which give figures for green alfalfa and for field-cured alfalfa hay.

TABLE 1.—*Weight and percentage of dry matter and protein in 1 ton of green alfalfa*[1]

Item	Total crop		Leaves		Stems	
	Pounds	*Percent*	*Pounds*	*Percent*	*Pounds*	*Percent*
Green crop	2,000	100	1,100	55	990	45
Dry matter	580	29	220	20	360	40
Protein in the green alfalfa	92.4	4.62	52.8	4.8	39.6	4.4
Protein in the dry matter on basis of no loss of leaves or stems	----	15.93	---	24.0	-----	11.0

[1] Basis of calculation: Leaves in green crop, 55 percent. Loss of leaves, 30 percent; of stems, 10 percent.

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[2] Italic numbers in parentheses refer to Literature Cited, p. 1075.

TABLE 2.—*Portions of the green crop saved or lost on curing*

Proportion saved or lost of—	Portion saved						Portion lost					
	Total crop		Leaves		Stems		Total crop		Leaves		Stems	
	Lbs.	*Pct.*	*Lbs.*	*Pct.*	*Lbs.*	*Pct.*	*Lbs.*	*Pct.*	*Lbs.*	*Pct.*	*Lbs.*	*Pct.*
Green crop	1,580	79	770	70	810	90	420	21	330	30	90	10
Dry matter	478	82.4	154	70	324	90	102	17.6	66	30	36	10
Protein of green alfalfa	72.6	78.5	36.96	70	35.64	90	19.80	21.5	15.84	30	3.96	10
Protein of crop		15.2		24.0		11.0		19.4		24		11

On the basis that during field curing there is a loss of 30 percent of leaves and 10 percent of stems, 1 ton of green alfalfa will yield 478 pounds of dry matter, consisting of 154 pounds of leaves and 324 pounds of stems. The amount of protein in the dried crop will be 72.6 pounds, of which 36.96 is in the leaves and 35.64 in the stems. When compared to the amount of dry matter and of protein in the 2,000 pounds of green alfalfa, these figures represent a loss of 102 pounds of dry matter during the curing process, equivalent to 420 pounds of the original green crop; and likewise a loss of 19.8 pounds of protein. In other words, 21 percent of the green crop (equivalent to 17.6 of the dry matter and 21.5 percent of the protein) was lost during field curing.

TABLE 3.—*Composition, digestibility, and digestible nutrients in field grass and early hay, on dry basis*

Constituent	Composition			Digestibility			Digestible nutrients		
	Fresh grass	Hay from field	Hay from stacks	Fresh grass	Hay from field	Hay from stacks	Fresh grass	Hay from field	Hay from stacks
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Fat (ether extract)	1.9	1.9	2.0	57.7	41.0	44.0	1.1	0.76	0.87
Crude fiber	24.6	24.0	26.9	77.5	76.3	77.9	19.1	18.3	20.9
Crude protein	11.8	12.2	12.9	68.9	66.5	48.5	8.1	8.1	6.3
Minerals (ash)	7.6	7.7	8.2						
Carbohydrate (nitrogen-free extract)	54.1	54.3	50.0	81.9	79.9	70.4	44.3	43.4	35.2
True protein	10.4	9.9	10.4	67.1	62.6	48.3	7.0	6.2	5.0
Lime (calcium oxide)	.67	.58	.72						
Phosphoric acid (phosphorus pentoxide)	.70	.70	.77						
Starch equivalent							63.7	55.0	47.0
Protein equivalent							7.4	7.2	5.7
Dry matter in fresh material	24.8	74.7	83.4	73.3	74.2	66.8			

The losses in field-cured hay have been apportioned by Wiegner *(1218)* as shown in table 4.

TABLE 4.—*Distribution of losses of dry matter and of starch equivalent as the result of field curing of hay*

Item	Dry matter	Digestible dry matter	Starch equivalent
	Percent	*Percent*	*Percent*
Respiration of crop	Up to 10	5–15	5–15
Mechanical injury	5–10	5–10	5–10
Fermentation in the stack	5–10	5–10	5–10
Metabolic processes in the animal			10–15
Total	10–30	15–35	25–50

On the basis of a 26,000,000-ton crop of alfalfa, the loss of dry matter and of protein would be 1,326,000 and 257,000 tons, respectively.

Besides this tremendous loss of protein and dry matter as the result of ordinary field curing, the loss of 30 percent of leaves during this process involves correspondingly large losses of calcium, phosphorus, and other essential minerals, for the leaves are the richest part of the plant in minerals as well as in protein and vitamins.

Watson, Ferguson, and Horton (*1194*) analyzed fresh grass, hay from the field, and hay from stacks with the results shown in table 3. Under quite different haymaking conditions, of course, the results might be materially different.

Losses in Curing

The classical researches of Fleischmann (*364*) in Germany constitute the most important contribution to the study of hay and the losses that take place during field curing. Until this study was made it was generally believed that if the hay was cut and dried under favorable conditions, unaccompanied by any loss of leaves, the dried hay retained unchanged, and in toto, the feed constituents present in the green crop, and that the only difference between the freshly cut grass and the field-cured hay was physical and in the moisture content.

Some of Fleischmann's general conclusions are well worth reproducing here. It is a question, of course, whether European data can be applied to this country, especially to those localities where drying of hay in the field can be completed in at most 2 days owing to continuous sunshine. In Europe because of rains or heavy dew field curing frequently requires several days.

(1) If hay is dried the same day it is cut the loss, if any, will be small.

(2) Slow drying (as on a sunless day) causes losses in dry matter of 4 to 13 percent. The longer the time required to dry, or the higher the temperature of drying in cloudy weather, the greater the loss of dry matter.

(3) The loss of dry matter ceases, however, when the partly dried hay still contains 38 percent of moisture (or, in other words, when hay has lost 87 percent of its original moisture) even though drying still be continued.

(4) The loss (about 9 percent) due to vital activity (enzymes) is considerably more than the loss (2 to 4 percent) due to micro-organisms.

(5) The drier the grass the greater the possibility of loss due to leaching from rain. When fresh or partly wilted grass is rained upon, the losses are due chiefly to activity within the cells. If wilted or dried hay becomes wet some loss may be caused also by bacteria.

(6) In live grass the loss due to bacteria is small. In dead grass this loss may reach 20 percent.

(7) In freshly cut and freshly made hay the content of lecithin (a fatlike substance containing phosphorus) averages about 88 milligrams per 100 grams of dry matter; in stored hay only 20 milligrams are left, a loss of 75 percent.

(8) The amount of protein nitrogen is always greater in the freshly cut grass than in hay (calculated on the same moisture content). On the other hand, the amount of amides (protein decomposition products) is always greater in hay. During haying there is always a loss of protein nitrogen but not of total nitrogen. This loss is due to activity within the cells. Freshly cut hay may contain as little as 9 percent of amide nitrogen and dried hay as much as 33 percent, especially if this hay has been dried under unfavorable conditions.

(9) There is always a loss of fat during haymaking, and this may be as high as 40 percent. This loss occurs whether the hay is dried in the sun or in the shade. The decrease in fat is correlated with the decrease in dry matter.

(10) No change has been noted in the crude fiber content.

(11) The loss of starch is significant if the hay is dried slowly, but when the drying is done quickly the loss is reduced to a minimum.

(12) The percentage of sugars decreases with the length of time of drying and with the temperature.

In a growing plant ingredients move from one part of the plant to another, especially toward maturity (*151*). In the drying of grass to hay there is a continuation of this interchange of ingredients.

According to Watson (*1187*), the losses by shattering of leaves, leaching, fermentation in the stack, the destruction of the carotene, etc., when hay is made in the ordinary way, may in the aggregate amount to 25 percent or more of the food value of the hay. Studies in Norway have shown average losses of 20 percent. In ordinary hay curing there is always a natural fermentation going on, with more or less production of heat, depending largely on the moisture content. The maximum temperature as the result of this fermentation is attained in about 10 days. A secondary fermentation is noted about 3 weeks after the hay is stacked. The highest temperature noted in some of these experiments was 150° F.

Under average conditions of haymaking in the British Isles the losses in feed value from harvesting to storing in stacks may amount to 30 percent or more of the starch equivalent and digestible crude protein, and in unfavorable weather these losses may even exceed 50 percent (*1189*).

The losses that take place in the field and in stacks with both early hay and ordinary hay were studied by Watson and his associates (*1194*), with the results shown in table 5.

TABLE 5.—*Losses of feed constituents that take place in curing hay*

Constituent	Losses					
	In field		In stacks		Total	
	Early hay	Ordinary hay	Early hay	Ordinary hay	Early hay	Ordinary hay
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Dry matter	18.0	14.3	5.2	5.7	23.2	20.0
Crude protein	14.3	18.5	2.2	2.7	16.5	21.7
Starch equivalent	34.5	26.7	6.8	5.3	41.3	32.0
Protein equivalent	23.0	33.7	9.0	[1] +4.3	32.0	29.4

[1] Gain.

During favorable years the losses of dry matter and of starch equivalent in ordinary hay averaged 8 and 20 percent, respectively; in bad years, 34 and 47 percent. With early hay the respective losses were 13 and 25 percent in good years, and 23 and 44 percent in bad seasons.

TABLE 6.—*Total nitrogen, protein nitrogen, and amide nitrogen in grass dried under different conditions*

How or where dried	Kind of grass	Length of time of drying		Temperature of drying	Dry substance	Nitrogen in water-free substance analyzed			Nitrogen in water-free original substance			Total nitrogen	
						Total nitrogen	Protein nitrogen	Amide nitrogen	Total nitrogen	Protein nitrogen	Amide nitrogen	Protein	Amide
		Days	*Hrs.*	°*C.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Vacuum[1]	*Festuca pratensis.*		3	98	23.0	2.29	2.01	0.28	2.29	2.01	0.28	88	12
Greenhouse	do	6	12	14	20.6	2.44	1.94	.50	2.18	1.73	.45	79	21
Cellar	do	7	12	11	21.1	2.43	1.78	.65	2.23	1.63	.60	73	27
Room	do	4	0	14	21.2	2.47	1.86	.61	2.28	1.72	.56	75	25
Vacuum[1]	*Poa pratensis.*		3	98	26.1	2.92	2.67	.25	2.92	2.67	.25	91	9
Greenhouse	do	7	0	15	24.1	3.30	2.36	.94	3.05	2.18	.87	72	28
Vacuum[1]	*Onobrychis sativa.*		3	98	20.2	3.36	2.98	.38	3.36	2.98	.38	89	11
Shade	do	5	0	16	18.8	3.66	2.45	1.21	3.36	2.25	1.11	67	33
Greenhouse	do	6	0	16	18.2	3.68	2.22	1.46	3.32	2.00	1.32	60	40
Wilted in cellar	do	7	0	13	19.0	3.54	2.00	1.54	3.32	1.88	1.44	57	43
Vacuum[1]	Mixed grass		3	98	22.0	3.91	3.31	.60	3.91	3.31	.60	85	15
In sun	do	5	0	9	21.1	4.06	3.11	.95	3.90	2.99	.91	77	23
Cellar	do	8	0	14	21.3	3.87	2.77	1.09	3.74	2.68	1.06	72	28
Vacuum[1]	Grass No. 1		3	98	21.6	3.15	2.83	.32	3.15	2.83	.32	90	10
In sun	do	2	0	19	20.7	3.22	2.63	.59	3.08	2.52	.56	82	18
Shade	do	3	12	20	19.5	3.44	1.90	1.54	3.10	1.71	1.39	55	45
	do	4	12	18	18.5	3.56	1.83	1.73	3.04	1.56	1.48	51	49

[1] Control.

Fleischmann's elaborately conducted experiments (*364*) in drying hay (1) in a vacuum, (2) in the greenhouse, (3) in the cellar, (4) in shade, and (5) in sun, show that under certain conditions nearly one-half of the protein may be broken down into amides. This is especially true when the hay is being dried for several days in the shade. When dried under good conditions, however, hay may contain as little as 10 percent of amide nitrogen (table 6).

The loss of leaves during the field curing of alfalfa under good conditions varies from 5.9 percent to 9.2 percent (see the article, The Nutritive Value of Harvested Forages, p. 968). This is an important factor, for leaves are the richest part of the plant in food nutrients. Leaves of cereal hays constitute one-fifth of the weight of the plant. After the milk stage these leaves contain nearly one-half of the minerals and 40 percent of the fat of the whole plant (*1091*).

Losses Through Leaching

Experiments conducted long ago in the Bureau of Chemistry showed that at least 30 percent of the phosphorus, 65 percent of the potash, and 20 percent of the nitrogen may be washed from dried plants by rain (*672*) More recent experiments by Guilbert, Mead, and Jackson (*446*) show that losses from leaching may be as high as 67 percent of the minerals, 35 percent of the carbohydrate (nitrogen-free extract), and 18 percent of the protein. Only a slight loss of fat was noted. The crude fiber content of leached plants was actually higher than before leaching, owing, of course, to the large losses of the other constituents.

Losses in Undercured or Wet Hay

It is well known that hay stored in mows or stacks in an undercured condition or cured hay allowed to become wet from any cause after storage is subject to excessive spontaneous heating, and such heating may progress to temperatures sufficiently high to produce ignition. The annual fire loss in the United States due to the spontaneous ignition of hay has been estimated as high as $20,000,000. The spontaneous heating may stop short of ignition, but even then the hay will suffer very serious deterioration and often complete destruction of its feeding value. Losses of this nature probably are even greater than the losses from fire.

In brown and black alfalfa, which is made by stacking partly wilted alfalfa with air excluded, Swanson, Call, and Salmon (*1112*) found enormous losses in protein, crude fiber, carbohydrate (nitrogen-free extract), and fat (ether extract).

Truninger (*1151*) found that excessive fermentation in storage resulted in losses of nitrogen-free extract as high as 40 percent. In only one case was the loss of digestible pure protein less than 50 percent, and in some cases it was complete.

Hoffman and Bradshaw (*526*) report very serious losses of organic substance in the storage of alfalfa of high moisture content. The losses involved chiefly the fats (maximum 47 percent), the sugars (maximum 94 percent), and the hemicellulose group—the more digestible portion of the plant framework (maximum 52 percent). Under the more extreme conditions cellulose and crude protein also were attacked.

It is generally agreed that the initial production of heat in a mass of undercured or wet hay is due mainly to the respiration process of the living plant cell and to the activity of micro-organisms. These agencies are capable of raising the temperature of the hay to as high as 158° F. or slightly higher. Temperatures above this (the death point of micro-organisms) cannot be due to biological causes. In the effort to account for the subsequent rapid rise of temperature that is necessary to produce ignition, various and sometimes conflicting hypotheses have been proposed. That of Browne (*162*) appears to be the most deserving of consideration. It is based on the assumption that micro-organisms in the absence of oxygen first produce unsaturated, highly unstable intermediate fermentation products whose subsequent oxidation generates the heat that may ultimately lead to ignition.

Losses of Vitamins

During sun curing of hay a considerable proportion of the carotene is destroyed Gordon and Hurst (*426*) show that sun-cured alfalfa contains 36 parts per million of carotene, or only about one-third that found in artificially dried hay. The relative amounts of carotene in sun-dried and artificially dried lespedeza was found to be 52 and 75 parts per million, respectively; in sorghum, 17 and 27; and in soybean hay, 42 and 64.

The carotene content of artificially dried grass was found by Watson (*1187*) to be 34.5 milligrams in 100 grams; that of A. I. V. silage, 46 milligrams; that of low-temperature silage, 39.5 milligrams; and that of meadow hay, only 1.5 milligrams. As much as 80 percent of the carotene may be lost during the first 24 hours after cutting (*998*), most of this loss being due to enzymic action associated with favorable moisture and temperature conditions. Hay cured away from ultraviolet light—for example, indoors—or by artificial heat in a drier retains most of its vitamin A (*1076*).

Intermittent sunshine and rain while alfalfa is in a swath causes the alfalfa to become bleached as well as to suffer an almost total loss (96 percent) of its vitamin A.

Vitamin B_1 in hay is present to the extent of 1 to 3 International Units per gram. This vitamin, being easily destroyed by heat, can deteriorate in storage and during the harsh treatment of curing to the point of almost total destruction (*1162*).

When hay is exposed to rain it loses a considerable proportion of its vitamin G. Exposure to dry weather even for 4 days did not, however, affect the G content (*561*).

While curing hay in the sun causes it to lose its vitamin A, curing in the absence of light prevents the development of vitamin D. Synthesis of vitamin D occurs only when alfalfa is cured in the sun (*1076*).

Artificially Dried Hay

Researches and experiments during the past few years have shown that methods other than field curing for the preparation of hay for storage were deserving of attention. The freshly cut grass besides being field-cured can now be ensiled, artificially dried, or, as is sometimes done in England, dried and compressed into "cakes." Ensiled or compressed hays have the advantage that they cannot easily be set on fire, whereas hay in stacks or in mows is always a fire hazard.

In the study of hay in the laboratory it was noted that when the hay was dried quickly in preparation for chemical analysis, it lost little or no dry matter, whereas the same hay dried in a cool, well-ventilated room lost 6 to 12 percent of dry matter (*364*). This difference quite naturally suggested quick drying of freshly cut grass in order to minimize the loss of dry matter.

At present only an insignificant percentage of the hay crop is thus quickly (or artificially) dried; in fact, not much over 100,000 tons. In the United Kingdom and on the continent of Europe a still smaller tonnage of hay is thus prepared

The object of drying green crops artificially is to retain the various factors that characterize hay of good quality. There are several types of driers—tray, belt, rotary, and pneumatic. These different forms of driers are as follows (*971*): (1) Tray driers are batch driers in which the grass is hand-shaken from one tray to another, halfway through drying, in order to facilitate even drying; (2) belt driers, in which the fresh grass is put in at one end and emerges dry at the other without handling; (3) rotary or drum driers, in which the grass is dried in a revolving drum, the herbage being agitated mechanically while under the influence of the furnace gas; (4) pneumatic driers, in which the grass is dried as it is carried along in the drying current.

The expense of artificial drying is an important consideration. A drying machine must pay for itself by producing a product of greater monetary and nutritive value than field-cured hay.

In artificial drying the losses of nutrient constituents, if any, should not exceed 5 percent unless excessive shattering of leaves takes place. In general, the temperature of drying is a minor factor in affecting the quality of the product, provided it is removed from the drier as soon as dry. So long as the plant has moisture that can be evaporated it will not be injured during the drying process. A pneumatic drier with an initial or inlet temperature as high as 1,472° F. may produce dry grass of excellent quality (*971*).

Experiments in drying grass indicate that the inlet temperature of 250° to 350° F. did not affect the digestibility of young dried grass, although with an initial temperature of 400° the grass lost appreciably in digestibility of the protein during 2 to 5 minutes of drying (*522*).

Other experiments show that a temperature of 480° to 535° F. for 40 seconds did not reduce the availability of the protein or calcium (*490*). Grass dried by direct heat in a kiln at 239° for 3 hours was only slightly less digestible than when dried with steam at 212° (*1257*).

It has been demonstrated that the temperature of the drying gas does not affect the carotene content of hay or the digestibility of the protein (*1187*), as table 7 shows.

Table 7.—*Carotene content and the digestibility of the protein of hay dried at different temperatures*

Item	Results at a gas temperature of— 176° F.	284° F.	482° F.	662° F.	1,112° F.
Carotene content, per 100 grams of dry matter . . milligrams	26.8	30.7	34.7	. . .	39.0
Digestibility of crude protein . . . percent	77.8	76.7	72.8	78.6	81.9

It has been shown by Kane and coworkers (*607*) that ordinary market hay may frequently contain as little as one-tenth the carotene in the green crop, and that alfalfa quickly dried in a tunnel drier at 260° to 264° F. may have as much as seven times the vitamin A content found in poor-quality hay; that when alfalfa was dried in a rotary drum, being momentarily exposed to a temperature of 1,200° to 1,382°, its carotene content was almost as high as in the freshly cut crops and 2 to 10 times as much as in the field-cured alfalfa. If, however, the artificially dried alfalfa is subsequently exposed to sunlight, it may lose much of its carotene. The amount of loss on exposure to sunlight is dependent largely on the temperature during the time the dry hay is exposed, there being no loss at 32° in 8 weeks' time. At 68° to 86°, however, the loss may reach 30 percent. Alfalfa can, therefore, be stored even in the light during the cold months without loss.

When, however, the green material has once become dried and is then kept exposed to hot air, there is a loss of both vitamin A and of digestible protein (*1188*) (table 8).

Table 8.—*Effect of excessive drying at various temperatures on the quality of hay*

Temperature (° F.)	Time of exposure	Carotene per 100 grams	Digestible protein	Temperature (° F.)	Time of exposure	Carotene per 100 grams	Digestible protein	Temperature (° F.)	Time of exposure	Carotene per 100 grams	Digestible protein
	Minutes	*Milligrams*	*Percent*		*Minutes*	*Milligrams*	*Percent*		*Minutes*	*Milligrams*	*Percent*
320	10	25.1	82.9	356	10	16.8	83.4	392	10	7.7	41.3
	60	4.7	46.4		60	2.0	27.8		60	0	9.9

Green pasture grass and the same grass after drying at different temperatures has been analyzed with the results shown in table 9 (*522*).

Table 9.—*Chemical composition of fresh and dried pasture grass, on dry basis*

Condition of grass	Dry matter	Protein	Crude fiber	Ether extract	Nitrogen-free extract	Calcium	Phosphorus
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Green	24.0	16.4	21.5	3.9	46.0	0.76	0.48
Sun-cured for 18 hours	92.2	18.8	20.5	3.5	44.6	.73	.65
Dried at 250° F	92.4	17.5	20.2	4.6	46.5	.73	.52
Dried at 300° F	92.7	17.8	21.0	5.1	43.8	.76	.56
Dried at 350° F	92.6	18.2	21.0	4.3	44.9	.67	.52
Dried at 400° F	93.2	18.0	22.9	5.0	42.5	.69	.58

McClure (*719*) gives equally interesting results after having analyzed green pasture, field-cured hay, and artificially cured hay (table 10).

TABLE 10.—*Composition of fresh, field-cured, and artificially dried hay, on water-free basis*

Condition of hay	Moisture	Ether extract	Ash	Crude fiber	Crude protein	Nitrogen-free extract
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Green	73.0	2.9	9.5	27.6	19.1	40.9
Field cured	16.9	2.1	6.9	28.2	13.7	49.1
Artificially cured	4.4	2.5	9.1	27.4	18.5	42.5

This same author found that drying at a temperature up to 250° F. did not injure the color of the hay, but concludes that artificial drying should not supersede field curing in localities where ideal haying conditions prevail.

Woodman, Bee, and Griffith (*1257*) give results showing the coefficient of digestibility of the constituents of freshly cut and of kiln-dried grass (table 11).

TABLE 11.—*Coefficients of digestibility of freshly cut and kiln-dried grass*

Constituent	Freshly cut grass	Kiln-dried grass	Constituent	Freshly cut grass	Kiln-dried grass
	Percent	*Percent*		*Percent*	*Percent*
Organic matter	79.3	79.4	Carbohydrate (nitrogen-free extract)	80.3	80.4
Crude protein	81.3	78.2	Crude fiber	80.2	81.0
Fat (ether extract)	57.2	73.7			

It is concluded that direct heat in a kiln does not depress the coefficient of digestibility.

While the temperature of the inlet gases (which come in contact with the young grass) may be as high as 302° F., the temperature of the grass itself never rises beyond 176°–194° so long as active evaporation of water is taking place.

In the use of a band drier, with inlet temperature of 392° F., grass was dried down to 10-percent moisture content in 10 minutes, the amount of digestible protein being only slightly depressed. When, however, grass was dried in a pneumatic conveyor in 15 seconds at 1,112°, the digestible protein was appreciably decreased (*1191*).

Artificial drying also saves space. Dried, chopped grass, for example, will require only about half the storage space needed for ordinary hay.

Young Grass

The artificial drying of young grass, or short leafy herbage, before the stemming stage or before the nodes appear is a relatively new idea in the production of hay. Such young grass is extremely rich in protein, fat, minerals, and vitamins. When it is cut weekly, the amount of protein in the grass after being dried may be as high as 21 percent; when cut at intervals of 3 weeks, the protein content will be about 19.3 percent; at 4-week intervals, 17.2 percent; and at 5-week intervals, 14 percent (*971*). The cutting and drying of young grass to make a concentrated feed is a more urgent problem in England than in the United States. The frequent rains in England also favor the growth of grass.

The composition and digestibility of fresh and dried young grass (table 12) have been studied by Watson (*1187*), the inlet temperature of the drier being 392° F.

Drying of young grass apparently does not affect the content of vitamins A, B, G, or D. The carotene is retained almost entirely. If, however, the grass is wilted for 6 hours before artificial drying, as much as 14 percent of the carotene may be lost. Young grass has been found to be effective in giving animals greater powers of resistance against disease. It has been noted, for example, that white scour in calves and udder troubles in cows are less frequent when dried young grass is fed (*971*).

TABLE 12.—*Composition and digestibility of fresh and dried grass, on water-free basis*

Constituent	Fresh grass		Dried grass	
	Composition	Digestibility	Composition	Digestibility
	Percent	*Percent*	*Percent*	*Percent*
Crude fiber	21.9	80.4	21.9	78.1
Crude protein	17.6	77.6	17.6	72.6
Carbohydrate (nitrogen-free extract)	44.9	77.5	45.9	77.0
Organic matter	86.5	77.3	88.5	75.7
True protein	13.1	70.8	16.9	72.2
Minerals (ash)	13.5	-	11.5	....

Instead of merely drying the young grass, so-called grass cakes have been made by first steaming the grass in troughs in order to dry it to less than 10 percent of moisture and then compressing this dried grass with a hydraulic press to a density such that 2,000 pounds occupied a space of 40 cubic feet. This grass cake contained 23 percent of protein, or 2½ times as much as is found in ordinary hay, and retained the original grass color (*1254*).

The percentage of fiber in dried young grass is less than in hay. Further, the fiber is practically as digestible as that of fresh grass. A yield of 3½ tons of dried young grass per acre is obtained when cuttings are made monthly. It is claimed that young grass provides more protein per acre than almost any other crop, except possibly marrow-stem kale.[3] One hundred pounds of dried young grass contains 13 to 14 pounds of digestible protein and 67 pounds of starch equivalent. A cow giving 5 gallons of milk a day will obtain all the protein, energy, and minerals required by consuming 33 to 34 pounds of dried grass.

After having been dried, young grass may be ensiled as well as compressed.

SILAGE

The curing or preserving of legumes and grasses by ensiling in order to produce high-quality roughage is not only a source of national wealth but is destined to play a role of paramount importance in the agriculture of the future.

Such a product is known as silage. According to one definition (*1193*) silage is a succulent fodder, made from fresh forage crops by storing them in a stack, trench, pit, or silo, from which air is excluded as much as possible; according to another, it is a preserved fodder that has acquired a more or less aromatic odor and an acid taste without putrefactive or moldy flavors (*53*); and according to a third, it is moist feed conserved in the absence of air (see The Nutritive Value of Harvested Forages, p. 981). Woodman and Amos (*1255*) divide silages into five distinct groups: (1) Sweet, dark-brown silage; (2) acid, light-brown silage; (3) green, fruity silage; (4) sour silage; and (5) musty silage.

Silos are of more recent origin than granaries. Columbus found that the Indians used pits or trenches to preserve their grain. But antedating that by centuries, Pliny tells of grain being stored in pits, as airtight and air-free as possible, in Greece, Spain, and Africa. Varro, who lived during the second century (116–27) B. C., relates how grain was kept for over 50 years in pits. It is also known that in ancient Egypt silos constructed of masonry were used for preserving grains.

In Metz, France, in 1707, there was uncovered a granary containing grain that had been stored in 1528 and that was still in such good condition that, it is claimed, good bread was made with flour milled therefrom. Green forage is said to have been preserved during the early history of the Baltic Provinces and in Sweden, where the uncertainty of the weather rendered difficult the proper curing of hay *(1251)*.

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[3] Daily Digest, U. S. Department of Agriculture, May 26, 1936. [Mimeographed.]

According to Samarani *(1003)* mention is made by John Symonds (University of Cambridge, 1786), of the ensiling of leaves by the peasants of Italy. The leaves were gathered in the cool of the day, allowed to wilt for 3 to 4 hours in sunlight, placed in wooden tanks that had been partly buried in the soil, compressed, and covered with earth. The tanks themselves were then covered with straw and more earth. This procedure is quite similar to the Crema process used today and described later in this article. In the course of time the buried tanks were modified into above-ground silos, made of wood, stone, concrete, and other materials. The present-day silos are in general not very different from those in use during the early years of the eighteenth century.

In 1875 Goffart, in a paper presented to the Société Centrale d'Agriculture de France *(25)*, related his experience with corn silage. He is reported to have said that at the time he purchased his farm in 1840, 8 scrawny cows and 120 sheep lived a miserable existence, whereas "today the same farm (300 acres) nourishes abundantly 68 cattle, 6 horses, and 300 sheep." The method of ensiling used at that time was somewhat similar to the American tower process. According to Woll *(1251)*, Goffart may justly be called the "father of modern silage."

The first silo built in the United States, also according to Woll, is said to be that erected by F. Morris in Maryland in 1876. With a yearly production of over 60 percent of the world corn output and the consumption of some 40 million tons of silage made chiefly from corn, the United States is justly known as the land of silos.

The amount of corn silage produced per acre in the United States ranges from 4 to 20 tons. Depending largely on the nature of the crop and the locality, as much as 40 tons of silage (in the case of sunflowers, for example) may be produced per acre. A corn crop that if allowed to mature would yield 50 bushels of shelled grain to the acre, would produce 8 to 12 tons of silage. A ton of ensiled corn would have yielded on the average only 5 to 5½ bushels of shelled grain *(1264)*.

The feed value of corn silage is evident when it is realized that 100 pounds of dry matter contain 4.3 to 4.8 pounds of digestible crude protein and about 40 pounds of total digestible nutrients *(521)*.

Though corn is the principal crop utilized for silage in this country, grass silage can be made as advantageously in many places, and sometimes more economically than field-cured hay.

Practices in different countries have shown that almost any herbaceous crops can be used singly or in combination in making satisfactory silage. These crops include corn, oats, and vetch, alfalfa, clover, and other legumes, timothy and other grasses, sunflower plants, beet tops, potato leaves and stems, soybean plants, and others. The only crops that do not lend themselves satisfactorily to ensiling are the root crops and those belonging to the Brassicaceae family (cabbage, kale, etc.).

Cured hay deteriorates in feed value, while ensiled grass can be kept a long time with relatively small loss. Further, there is never any loss of ensiled grass as the result of farm fires, whereas 20 percent of the 150 million dollars' worth of farm property destroyed by fire each year is due to spontaneous combustion of stored hay. Grass silage contains about 70 percent of water and will not burn. There is relatively little loss of protein and dry matter--generally not more than one-fourth of the starch-equivalent or one-twentieth of the protein—in good silage compared to the losses of these constituents in haymaking even under favorable weather conditions.

Immature grasses, as a rule, make better and more palatable silage than do mature crops. The same applies to the making of hay. The chopping of grasses and legumes increases the amount of material that can be ensiled. Partial drying also increases the amount of dry matter than can be stored in a given space, but it tends to increase the surface spoilage (*1267*).

It is generally admitted that good silage can be made in all types of upright silos if they are airtight. Silos with a gravel or concrete floor and with an open drain generally produce the most uniform silage, although many good silos are not provided with drains (*821*).

Data given by Hosterman (*543*) and by Hamlin (*463*) show that the space occupied by silage is approximately 44 cubic feet per ton, as against 470 to 485 cubic feet per ton for stacked alfalfa or 625 to 640 per ton for stacked timothy. Large bales (box-pressed) of hay require about 200 cubic feet per ton, whereas the small or common bale will occupy from 100 to 150 cubic feet.

The study of the chemical changes that take place during the ensiling process was first undertaken about 50 years ago. Today a vast and impressive literature confronts the student of this question. In the light of present knowledge—and lack of knowledge—the following conclusions would seem to be justified:

1. In making silage it must always be kept in mind that air is enemy No. 1, and that silage which becomes heated consumes itself.
2. Undue or excessive losses are obviated either by the quick development of carbonic acid, as when heavy pressure is used in the Crema process, or by the production of sufficient acid to overcome the ravages of bacteria and other organisms, as in the making of ordinary corn silage.
3. The use of silage made by the addition of mineral acids or by the use of chemical sterilizers has not been proved safe beyond question, in long-time feeding procedure.
4. The use of such chemicals must for some time be looked upon with suspicion and in most cases rejected in favor of the more natural processes. Apparently the best method of supplying materials to the animal (and this refers to the use of phosphoric acid and other acids or chemicals used in making silage) is through the feeding of forages naturally rich in minerals that have been taken up from the soil and metabolized by the plant.
5. It is a question whether silage prepared by the addition of mineral acids can be considered as beneficial to the animal as are silages in

which the acids of the organic type have been naturally formed.

6. The question whether lactic acid made by the farmer himself from some of his waste farm products can be economically and successfully used in silage instead of mineral acids may be worthy of study.

7. The vast amount of data, much of it inconclusive, reported by the various workers in this field indicates the necessity for concerted cooperative study of silage questions. For example, what kind of silo should be used under various conditions—with various crops harvested at different stages of growth, in different localities, under different weather conditions, by different processes, and with the aid of various added substances, chemical or otherwise?

8. The methods of sampling silage for analysis and the basis used for the calculation of results may lead to erroneous conclusions regarding the feed value of the silage. These sources of error should be eliminated.

9. The variation in the loss of dry substance resulting from the ensiling of different crops by different processes is of great economic importance. For example, with a consumption of 40 million tons of silage a year, a loss of 5 percent of dry matter would be equivalent to over 2 million tons of feed and a loss of 15 percent would mean that farmers would have fully 7 million tons less of feed at their command.

10. Practically no information is available regarding the effect of fertilizers, soil treatment, and other factors on the quality of silage produced from the same crop grown in different localities or under differing systems.

11. Little or no information is available regarding the relative effect of added mineral acids and of naturally formed organic acids on the character and utilizability of the mineral constituents of silage and of some of the important organic constituents.

12. Under certain favorable conditions the losses in haymaking are less than in ensiling (*472*, *1256*). The silo, however, is a means of saving considerable feed, which, if field-cured under ordinary or unfavorable conditions, would suffer appreciable loss. Silos can be filled in almost any kind of weather. Silage is an emergency feed.

13. Protein-rich crops—that is, crops with a ratio of 1 part of protein to 2 parts or less of carbohydrate—are generally most successfully ensiled if mineral acids or molasses is added (*414*).

14. Carbohydrate-rich crops—that is, crops with a ratio of 1 part of protein to more than 2 parts of carbohydrate—can be ensiled without any addition of sugar or acid if they are ensiled in a moist condition.

DATA ON LOSSES AND FEEDING VALUES IN SILAGE

Beginnings of Experimental Work

In 1883, Weiske and Schulze (*1199*) made silage experimentally for the purpose of studying some of the changes resulting from the process of ensiling green crops. Subsequently many other scientists, both in this country and abroad, engaged in the study of this question. Grandeau, of France, was one of the first to observe in silage the presence of acetic and lactic acids. At the Pennsylvania Agricultural Experiment Station a stone-basement root cellar was used as a silo; in the course of 3 years' experimentation a loss of 5 to 12 percent of dry matter was noted, chiefly of carbohydrates other than fiber (*906*).

Henry and Woll (*508*) noted a loss of dry matter of 22 to 24 percent, the largest losses being in carbohydrate (nitrogen-free extract), protein, and fiber. There was a gain in fat (ether extract), an observation that has been corroborated by many workers in this field, making it reasonable to assume that during the ensiling process some ether-soluble compounds may be produced. These authors furthermore noted a loss in ash, due, it was claimed, to the movement of juices of the green fodder and to diffusion.

Armsby (*34*) and Jordan (*596*) proved by feeding tests that the process of ensiling caused a loss of nutritive value. Hills (*514*) and Collier (*855*) also demonstrated that there was a loss of dry matter, while Babcock and Russell (*53*) were the first to point out the role played in silage by bacteria.

Theory of Silage Formation

Russell (*994*) in 1908 made a very clear and concise explanation of what goes on during the process of making silage, and this has been somewhat further elaborated by Peterson, Hastings, and Fred (*918*).

When green plants are ensiled in an airtight silo, the plant cells continue to function, that is, to respire, producing carbon dioxide with gradual exhaustion of any oxygen that may be present. The sugars are thus consumed in the absence of air or oxygen, complete oxidation being impossible. The intermediate products—alcohol and acetic, lactic, and butyric acids (besides carbonic acid and water)—are probably all formed as the result of the activity of enzymes within the cells. Enzymes also act on the proteins to form amino acids, peptides (valuable protein break-down products), and even ammonia. Because water vapor is largely retained, the temperature of the mass in general is raised somewhat, thus causing greater cell activity, but as the fresh material becomes exhausted the cells die, becoming flaccid and causing the mass to settle. At this time the temperature falls somewhat.

Coincident with the decreasing activity of the plant cells comes an increase in the activity of bacteria, yeasts, and molds, causing a secondary rise in temperature. Molds, however, cannot grow without air and cease to reproduce as soon as the oxygen has been consumed. Yeasts disappear within a few days, leaving only the bacteria as active agents. According to Watson and Ferguson (*1193*) the changes during ensiling are of two kinds: (1) Those occurring while the cells are still alive, and (2) those that come into play after the cells are dead, when the activity of micro-organisms sets in.

Most of the changes characteristic of silage—for example, the disappearance of sugar and of the less resistant cellulose, the formation of acids, and the breakdown of proteins—are the result mainly of the activity of enzymes within the cells—the primary factors in silage fermentation. The changes brought about by bacteria are regarded as being for the most part secondary. Certain workers in this field claim, however, that because lactic acid bacteria are present in such large numbers in silage their chemical activities cannot be disregarded (*837*). Typical of the products of bacterial activity are formic acid, higher fatty acids, humus, and amines (protein decomposition products).

The work of Babcock and Russell of Wisconsin (*53*) who first showed that if bacteria are destroyed and enzymes only remain active in silage there will be no mold formation, no loss of dry matter, and no change in acidity, has been corroborated by Russell of England (*994*). While proteins may be changed to nonproteins there will be no loss of total nitrogen.

Russell's experiments were conducted on a laboratory scale, green maize being ensiled in bottles. Table 13 shows the results obtained at the end of 5 months.

It is evident that in the absence of air the volatile acids are formed by the protoplasm of the living cells, as the result of anaerobic respiration (with little or no oxygen); and that the break-down of the protein nitrogen to nonprotein nitrogen is a function primarily of the enzymes and secondarily of bacteria, as certain amino acids found in silage are characteristic of bacterial action. The presence of air results in mold formation, musty smell, and freedom from organic acids, the product even becoming alkaline. It might be concluded also that in the presence of air an appreciable quantity of protein may be synthesized from nonprotein nitrogenous compounds, as has been noted in stored barnyard manure.

According to Esten, Christie, and Mason (*336*), sugar—which amounts to about 3 to 4 percent in green-cornstalk juice—mostly disappears during fermentation on ensiling, and the percentage of acid found in the silage is about equivalent to the percentage of sugar originally found in the fresh crop. The alcohol formed largely disappears also, having been oxidized to acetic acid through some kind of fermentation by a combination of yeasts and bacteria, both of which are present in large numbers in freshly made silage. The acid bacteria grow until they produce enough acid to inhibit their own growth, when they die, but yeasts are still able to grow in such a medium and continue to convert sugar to alcohol, which in turn is finally oxidized to acetic acid.

TABLE 13.—*Effect of protoplasm, enzymes, and micro-organisms, under aerobic and anaerobic conditions, upon the formation, in silage, of volatile acids and ammonia*

All air excluded				Air present
Living maize—protoplasm, enzymes, and bacteria active	Maize plus toluene—enzymes only active	Maize plus heat at 98° C.—spore-forming organisms only active	Maize plus silage juice—protoplasm, enzymes, and micro-organisms present	Living maize—protoplasm, enzymes, and bacteria active
Silage formed. No mold. Dry matter lost, 25 percent. Mass became acid. Acetic and butyric acids formed. Protein changes to nonprotein. No loss of nitrogen in form of ammonia.	No obvious change. No mold. No loss. No change. No volatile acids formed. Protein changes to nonprotein. No loss of nitrogen as ammonia.	No obvious change. Little mold. Dry matter lost, 12 percent. No change. No volatile acids formed. No change in protein No loss of nitrogen in form of ammonia.	No obvious change. No mold. Dry matter lost, 25 percent. Mass became acid. Acetic and butyric acids formed. Protein changes to nonprotein. No loss of nitrogen in form of ammonia.	Putrefaction. Much mold. Dry matter lost, 60 percent. Mass became alkaline. No volatile acids formed. Nonprotein changes to protein. Much loss of nitrogen as ammonia.

Among the acids formed, lactic and acetic appear to have a favorable effect on the quality of the silage, while butyric acid, which is the result of imperfect methods of ensiling and of putrefactive processes, injures the silage as a feed.

The presence of acid is one of the criteria of good silage. The role of organic acids is as a preservative, for bacteria cannot grow except in a neutral or alkaline (or only slightly acid) medium. If air is kept excluded—that is, if anaerobic conditions are maintained—the acidity formed in silage during the first 2 weeks is sufficient to check decomposition. Esten, Christie, and Mason (*336*) regard the process of acid formation in silage as identical to that in the making of sauerkraut. The amount of acid in silage is from 1 to 2 percent. In a 100-ton silo there are from 2,000 to 3,000 pounds of mixed organic acid. An animal consuming 40 pounds of silage a day will ingest an amount of acid equal to that in 7 pints of vinegar.

Fully 90 percent of the volatile acid found in good silage is acetic; propionic acid is next in amount. Butyric acid is found only in silage that shows evidence of spoilage. Lactic and acetic acids are always found in silage, irrespective of the kind of silo construction or the type of silage, according to Dox and Neidig (*280*).

The most obvious phenomena in silage making are, therefore, a rise in temperature (depending on the conditions under which the silage is made), changes in the color of the silage, the development of acids due to the oxidation of carbohydrates during cell respiration in the absence of air, the production of an aromatic odor, and the break-down of the proteins by hydrolysis.

Silage from Different Types of Silos

Trench Silage

Experience has shown that green crops ensiled in trenches—an old method—make one of the cheapest forms of silage, superior to that made in a clamp (pit stack) or ordinary stack. In a pit or trench there is little loss from the molding of silage on the sides of the pit, whereas in a stack this loss is appreciable. The temperature attained in the material ensiled in a pit, owing to the relative compactness and the absence of air, is considerably lower than in a stack. The protein of pit silage is hence more digestible.

In a trench silo, the average loss of digestible crude protein ranges from 0 to 5 percent (in the case of good-quality silage), and the loss of the starch equivalent averages 10 percent. So long as there is an adequate supply of sugar from the material ensiled and the silo is properly constructed, the formation of butyric acid, even in high-protein material, will be largely prevented.

Stack Silage

Stack silage, which is probably the oldest form of silage, requires no capital outlay. As prepared, it frequently shows a loss, from spoiled silage and silage unfit for feed, of nearly 30 percent of the dry matter. About 50 percent of the material in the center of the stack is, however, good sweet silage; the remainder, amounting to 20 percent more, is still edible, though it contains some butyric acid.

Comparative tests conducted for 3 years at the Washington Agricultural Experiment Station (*521*) of silage in silos and in stacks show that while the losses of dry matter from spoilage were about 7 percent in the silo and 10 percent in the stack, the losses from other causes averaged nearly 25 percent in both silo and stack. The greatest losses occurred during the years when the material was ensiled in a wet condition. The recovery of silage, as measured by samples in bags and by total weight in a silo and in a stack is as shown in table 14.

TABLE 14.—*Average recovery of feed constituents of silage*

Basis	Dry matter	Protein	Fiber	Fat	Carbohydrate (nitrogen-free extract)	Ash
Total weight:	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Silo	76	84	83	79	69	87
Stack	76	75	86	87	65	114
From bags:						
Silo	86	88	92	111	76	89
Stack	78	75	92	97	68	91

Clamp Silage

What is known as "clamp silage" in England is similar to silage made in the so-called pit stack frequently found in the West, where a tractor is sometimes used to compress the material ensiled. This form of silage requires very little, if any, expense other than that of digging the pit, but it is difficult to make the silage without considerable loss—greater loss, in fact, than there is in most other forms of silage. The wastage on the top and sides may be as high as 25 percent, and the smaller the clamp the greater the loss; hence this form of silage should be made only on a large scale. Further, considerable sour silage is apt to be found at the bottom, owing to the very tight packing of the ensiled material by horse and cart (the English way) or by tractor. When succulent materials are ensiled and low temperatures are maintained, as often is the case with sour clamp silage, butyric acid, which accompanies putrefactive changes, may develop. Ammonia and other useless or harmful substances may also be produced at the expense of the proteins (*1256*). The best that can be said of clamp silage is that it is useful in saving green fodder in a succulent form when conditions are unfavorable for haymaking. The trenches used in the United States appear to preserve the silage more effectively than the British clamp silos. In the Southwest particularly, trenches are being used to preserve various forage crops. If the trenches are well drained and the material is covered and packed to exclude air, the losses of nutrients may be little if any greater than in tower silos.

Tower Silage

Green material ensiled in a tower silo is generally chopped into small pieces and blown into the silo. Almost any kind of green crop may be used, although in the United States corn is the principal crop thus ensiled.

Study of the transformations that take place in ensiled corn show that in 1 day after the silo is filled, the oxygen is reduced practically to zero and carbonic acid increased to 45 percent of the silo gas. In 2 days the percentage of carbonic acid is approximately 70. From this point the relative amount of this gas decreases, so that at the end of 131 days less than 20 percent is left. The moisture content, which approximates 65 to 75 percent at the time of filling, remains practically constant during the ensiling process. The acidity of the juice gradually increases (from pH 5.9 to pH 4.0 or less), and the sugars decrease from over 8 percent to less than 2. At the time of filling, the amount of soluble nitrogen is about 18 percent of the total nitrogen, whereas at the end of fermentation the amount of soluble nitrogen is approximately 45 percent divided about equally between soluble protein and amino acids plus peptides (*918*).

The loss of dry matter in good corn silage is about 10 percent. During the fermentation no trace of hydrogen, methane, or other hydrocarbons (all decomposition products of little or no feed value) is ordinarily found.

That bacteria play an important role in the production of organic acids and alcohol is indicated by the appearance of large numbers at the time of most active fermentation. Bacteria found in silage grow best at a temperature of about 90° F.

From the study of the process of making ordinary corn silage, Peterson, Fred, and Verhulst (*917*) concluded that 15 to 20 percent of the pentosans (carbohydrates of somewhat less feed value than starch) were lost during fermentation at the end of 50 days. Other investigators have shown that as much as 30 percent of the pentosans may be lost, leading to the conclusion that pentosans as well as the ordinary carbohydrates may also be active in the production of organic acids (*994*). When green maize in sappy condition, containing as much as 78 percent of moisture, is ensiled, the loss of dry matter due to respiration and bacterial action is considerably higher—25 percent or more (*1256*).

When corn containing only 12 percent of dry matter was compressed in watertight vats, it lost about one-fourth of its dry substance; but when it was loosely packed the loss of dry matter was nearly 36 percent in 115 days, while the loss of protein was over 50 percent (*1199*).

Woodman and Amos (*1255*) found by analyzing samples taken from bags placed at different heights in various silos that the percentage loss (or gain) of constituents varied as follows: Moist material, 1.5 to 11, loss; dry matter, 5.8 to 11.8, loss; organic matter, 6.3 to 12.9, loss; crude protein, 2.0, gain to 12.2, loss; fat (ether extract), 59 to 122, gain; carbohydrate (nitrogen-free extract), 16.2 to 24.9, loss; crude fiber, 0.9, gain to 11.8, loss; minerals (ash), 3.1, gain to 6.8, loss; true protein, 11.8 to 55.3, loss; amides, 60 to 167, gain. The immature crops suffered the greatest hydrolytic changes in the protein; over 50 percent of the protein was broken down by hydrolysis, and this increased the amides by 150 percent.

Experiments conducted by Hansen (*472*), with the American tower silo in connection with such varied crops as vetch fodder, potato leaves and stems, clover, frozen beets, and meadow grass showed losses in dry matter as the result of ensiling as shown in table 15.

TABLE 15.—*Losses or gains in feed constituents as the result of ensiling various crops*

Constituent	Vetch	Potato stems and leaves	Clover	Frozen beets	Meadow grass
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Weight of fodder	−10.9	−17.8	−9.8	−38.8	−25.5
Dry matter	−30.6	−29.8	−20.7	−26.5	−26.3
Crude protein	+8.7	−11.9	−22.3	−33.0	−24.7
Pure protein	−29.2	−40.0	−29.1		−30.0
Nonprotein	+152.7	+531.8	+16.2		+3.3
Crude fat	−31.8	−35.2	−51.4	−38.8	−45.0
Nitrogen-free extract	−46.7	−46.5	−20.3	−30.1	−33.5
Crude fiber	−10.8	−14.3	−16.2	−35.6	−10.5
Pure ash	−6.7	−22.1	−32.6	−16.6	−32.0

From these experiments it was concluded that appreciable quantities of feed values were lost from each kind of material—even more than in ordinary haymaking. It was recommended, however, that when good hay cannot be made because of weather conditions, ensiling is worth while on any farm. Much feed can thus be saved that otherwise would be lost.

The losses of carbohydrates and of dry matter in different kinds of silage made from oats and vetch ensiled in a tower silo and in a clamp silo were determined by Woodman and Hanley (*1260*) with the results shown in table 16.

TABLE 16.—*Loss of dry matter and of carbohydrates in different kinds of silage*

Item	Tower silo		Clamp silo	
	Acid brown	Green fruity	Sour	Sweet
	Percent	*Percent*	*Percent*	*Percent*
Carbohydrates	14.7	19.1	45.9	20.5
Dry matter	7.7	11.2	23.4	11.5

A special study of acid-brown silage and of so-called fruity silage was made by Woodman and Amos (*1255*), who noted the gains or losses of constituents (table 17).

TABLE 17.—*Losses or gains of feed constituents in acid-brown and green fruity silage*

Constituent	Average of 8 trials		Constituent	Average of 8 trials	
	Acid-brown silage	Green fruity silage		Acid-brown silage	Green fruity silage
	Percent	*Percent*		*Percent*	*Percent*
Dry matter	−7.7	−11.2	Crude fiber	−6.0	−5.5
Crude protein	.0	−8.2	Ash	.0	−9.2
Ether extract	+45.0	+52.4	True protein	−28.4	−41.0
Nitrogen-free extract	−14.7	−10.1	Amides	+96.0	+85.3

Silage Made by Different Processes

No effort will be made here to cover silage made by all the known processes, but only those prepared by the most widely used or the most approved methods.

In some cases the studies have been made with experimental lots of silage in small jars. Other studies have been made in small silos, constructed to simulate large farm silos. It is generally admitted that for the best comparative results indicative of what goes on in practice in a large silo, the amount of silage used in experiments of this kind should be at least 8 to 10 tons. However, results obtained on a small laboratory scale are very useful in arriving at the amount of the various constituents lost during ensiling.

The A. I. V. Patented Method

The method developed by A. I. Virtanen, Valio, Finland, between 1925 and 1929, consists of adding to the green crop (grass or legume) the so-called A. I. V. solution at the rate of about 17 gallons per ton of fresh material. This A. I. V. solution consists of concentrated hydrochloric acid (5 parts) mixed with concentrated sulfuric acid (1 part), the mixture being diluted with 4 to 5 volumes of water to form what is known by chemists as twice normal strength of acid. The object is to increase the acidity of the green crop as soon as possible (to a pH value of 3.0 to 4.0). Such a degree of acidity suppresses bacterial fermentation as well as respiration in the cells, thus preventing spoilage of the ensiled crop. With an acidity of pH 4 or below (the lower the number on the pH scale, the greater the acidity), there is little destruction of the proteins or vitamins.

Watson and Ferguson (*1192*) ensiled a mixture of grasses and clover (moisture content 82 percent, dry matter 18 percent), filling the silo to a depth of 24 feet and using some 15 gallons of the dilute (twice normal) mixture of these mineral acids per ton. With pH 3.7 the carotene in the silage amounted to 57 milligrams per 100 grams of dry matter. This is essentially the same amount as is found in green grass, but somewhat more than in even artificially cured hay. In field-cured meadow hay, as is well known, the amount of carotene is much lower, only about 1 to 3 milligrams (*1256*). This is good evidence that in properly ensiled grass the vitamin A potency remains high. Somewhat later, Watson (*1189*) made seven accurate trials, conducted at Jealott's Hill, with silage prepared by different methods. The results showed that the loss of dry matter by the A. I. V. process was 17.7 percent as against 18.2 percent by the ordinary ensiling method, 16.1 percent in the case of silage with added molasses, and 17.7 percent in silage with added whey. The loss of protein was 3.8 percent in A. I. V. silage, 5.7 percent in ordinary silage, and 5.4 percent in silage containing molasses, while with silage containing whey a gain was recorded.

These results are at variance with those obtained by Virtanen (*1169*), whose experiments indicated that A. I. V. silage suffers not over 8-percent loss of dry matter, in most cases the loss being nearer 3 percent.

Recent experiments conducted at the Rowett Institute (*569*) demonstrate again that there is little if any difference between fresh timothy grass and the same grass ensiled by the A. I. V. process in quantity of dry matter, crude protein, true protein, and soluble protein. The addition of mineral acids to grass lowers the palatability but maintains the high carotene content and preserves the dry matter. The comparative absence of ammonia in A. I. V. silage was recently corroborated by Peterson, Bird, and Beeson (*915*).

Silage Made With Added Molasses

While it is perfectly feasible to ensile high-carbohydrate crops successfully because the acids, produced at the expense of the sugars and starch, act as a preservative agent, it is more difficult to ensile a protein-rich, high-moisture crop by the same method without undue loss. In the case of crops with low sugar and starch content, the development of organic acids in sufficient amounts to act as a preservative is prevented. Hence it has been suggested that when green grass or legumes are to be ensiled, some fermenting material be added.

Reed and Fitch (*952*) were the first to add molasses (5 to 10 percent by weight) to alfalfa and to show that alfalfa so treated had a higher degree of acidity than when no molasses was added. The moisture in the crop was 60 to 70 percent. Other investigators (*850*), however, have failed to find that the use of molasses increases the acid content of alfalfa silage, although it does apparently improve the palatability. Woodward (*1267*) is likewise of the opinion that the main advantage of adding molasses to grasses with relatively high moisture content is to improve the palatability of the silage.

Swanson and Tague (*1113*) ensiled alfalfa with molasses, germinated corn, and sound corn, and obtained the best results with molasses.

With grasses or cereals some 40 pounds (3½ gallons) of molasses should be used per ton; with mixed grasses and legumes, 60 pounds (5 gallons); with alfalfa or clover, 80 pounds (7 gallons); and with soybeans, 100 pounds (8½ gallons). These amounts have been found to answer the purpose and to yield a palatable silage (*821*). In general, the higher the protein content of the crop, the more molasses should be used.

While the losses in silage made with molasses are somewhat greater than in that made by the A. I. V. process, the production of silage with mineral acids entails a great deal more labor and delay than does the production of natural fermentation silage (*281*), or one to which molasses has been added. Further, the addition of molasses is better adapted to farm routine than is the use of mineral acids (*143*). Unlike acids, molasses does not injure the concrete or masonry of the silo and is not troublesome to use, and silage made with it does not need to be neutralized with ground limestone as is the case when mineral acids are used. Again, silage containing molasses is much more palatable than A. I. V. silage.

Silage Made With Added Whey

When ordinary whey is added as a substitute for molasses to a protein-rich green crop, satisfactory conservation of the silage is not possible. Excellent silage can be made, however, by the use of dry or concentrated whey either alone or inoculated with lactic acid bacteria. No greater losses were noted in such silages than were found in silage made either with molasses or by the A. I. V. method (*17*).

Defu Solution

A modification of the A. I. V. process consists in using hydrochloric acid to which was added a small amount of phosphoric acid. One and one-fourth gallons, or 16 pounds, of a mixture of these acids are diluted with 4 to 5 volumes of water, and this dilute solution is mixed with the green crop at the rate of 10 gallons per ton. When properly used, phosphoric acid makes good silage, causing the formation of lactic acid. Defu acid is said to have a favorable effect on the retention by animals of the calcium, phosphorus, and nitrogen present in feeds (*463*). According to Kirsch and Feeder (*632*), the use of the Defu solution resulted in a good silage, the loss of dry matter having been cut fully one-half.

When this Defu solution (to which a small percentage of sugar was added) was used with pasture grass in an ordinary silo and in a pit (according to the Dutch method), the silage in the silo had lost 20 percent of the protein and 11 percent of the total organic matter at the end of 3½ months, and that in the pit 68 and 24 percent, respectively. The acid in the pit silage was chiefly butyric, that in the silo chiefly lactic. The acidity of the silo silage expressed as pH was 3.7, and that of the pit silage 5.3 (*159*).

The Samarani or Crema Process

The Samarani (*1003*) or so-called Crema method is a low-temperature fermentation method developed at the Bacteriological Station at Crema (Lombardy), Italy, and consists in tightly compressing a partly wilted crop (moisture content 35 to 45 percent) in an airtight silo. The top is weighted with a load of 600 to 2,000 pounds per square yard of area, and this, in a way, acts as a seal.

The carbon dioxide produced as the result of respiration within the cells of the vegetable tissue displaces the oxygen within a few hours and acts as a preservative. The theory is that if there is no access of air, the ensiled partly wilted crop will not heat and hence not spoil.

When corn is ensiled by the American method in too dry a condition, it is often the practice to add water, and this demonstrates how different are the American and Italian theories of ensiling. In the American method the object is to hasten the development of acid in the silage. In the Samarani process every effort is made to prevent fermentation and to keep down the formation of more than a minimum of acidity.

The essential factor in the Crema process is the reduction of the moisture content of the crop to a point where bacterial growth is hindered with subsequent control of fermentation, yet at the same time to retain sufficient enzymic activity in the plant cells to consume the oxygen.

Whereas the loss of dry matter in silage in open ditches may amount to as much as 40 percent (the loss of dry matter in corn silage in a tower silo is about 10 percent), the loss in Crema silage prepared in sealed silos is much less; there is little loss of sugar and no more than 10 percent of the protein is broken down by hydrolysis. It is being recognized more and more that fermentation and heating of ensiled material should be reduced to a minimum. Heating to 113° F. and over, as in the old style open silo, consumes the sugars and starch and reduces the nutritive value of the protein, calling to mind the old saying "silages which become heated consume themselves." Sealed silos of the Crema type prevent all undue heating of the mass; there is little acidification and a minimum loss of dry matter or of nutritive value.

Toro-Silon

The addition of certain sterilizing agents has been proposed for the purpose of inhibiting bacterial fermentation and preventing the break-down of protein by plant enzymes. This treatment of green crops for silage purposes is exemplified by the so-called Toro-Silon process, which consists of adding a mixture of formaldehyde and sulfurous acid. According to Kirsch and Feeder (*632*), this treatment has no favorable effect on the quality of the silage or the prevention of losses, and these authors consider that it is useless.

The Effect of Acidity

Some 63 samples of silage, made from grass and forage crops, were tested by Watson and Ferguson (*1193*) for true protein, volatile bases (such as ammonia), and amino acids, and it was noted that silages with relatively low acidity (greater than pH 4.5) contained a smaller percentage of pure protein and a higher percentage of ammonia than the same silages with high acidity (less than pH 4.0). In a general way this agrees with the results obtained by other investigators who, on the basis of 83 samples, showed that those with a pH value less than 3.5 averaged 5.9 percent ammonia nitrogen, whereas those with a pH value greater than 5.0 contained 27.4 percent of the total nitrogen in the form of ammonia. This represents a definite loss of protein.

From a study of the effect of acidity on the presence of organic acids, it appears that silage with high acidity (low pH) averages considerably lower in volatile acids (chiefly acetic acid), but higher in residual acidity (lactic acid). The more lactic acid and the less acetic acid formed in silage, the better the silage as a rule.

Butyric acid is, as a rule, not found in silage of high acid content (with pH 4.2 or less). The acidity of silage also materially affects the ratio of volatile to fixed acids. Silages prepared from grass, grass and molasses, and grass and A. I. V. acid were studied by Watson and Ferguson (*1193*), who found that when the acidity was high (less than pH 4), there was three times as much fixed acid (lactic) formed as volatile acid (acetic). When, however, the acidity was low (greater than pH 4.5), there was over twice as much volatile as of fixed acid. In other words, nonvolatile or fixed acids (chiefly lactic) decrease with an increase in pH value and vice versa. This applies in a general way to butyric acid (also volatile) as well, for when the acidity is relatively low (greater than pH 4.5), the amount of this undesirable acid increases appreciably.

The figures from experiments conducted by Watson and Ferguson (*1193*), given in table 18, show the relative amounts of total acetic acid and of total butyric acid under different pH values and in different kinds of silage. It will be noted that a low acidity (high pH value) in silage is correlated with a high percentage of butyric acid.

TABLE 18.—*Amount of acetic and butyric acids in silages with different pH values*

Kind of silage	pH value	Acetic acid	Butyric acid	Kind of silage	pH value	Acetic acid	Butyric acid
		Percent	*Percent*			*Percent*	*Percent*
Grass	4.32	0.61	0.11	Grass and molasses	5.88	0.50	0.39
Do	5.21	.36	1.42	Grass and mineral acid	2.48	.25	.08
Grass and molasses	3.89	.67	.04	Do	4.82	.47	.68

Experiments conducted at the experiment station at Gembloux by Piraux, Hacquart, Joassin, and Desmet (*927*) also show that the higher the pH value of silage the more butyric acid it contains. (Table 19.)

TABLE 19.—*Amount of butyric acid in silage with different pH values*

Kind of silage	pH value	Butyric acid in fresh silage	Kind of silage	pH value	Butyric acid in fresh silage
		Percent			*Percent*
Warm fermentation in towers	4.1	0.23	Cold fermentation, plus molasses	3.9	0.09
Warm fermentation in stacks	4.7	.56	Silage plus mineral acids	3.5	.00
Cold fermentation	4.3	.52			

Drainage Losses

Drainage samples were collected by Godden (*415*) every 2 hours each day for 20 days—that is, during the period of flow—and, on analysis, 47 to 82 pounds of dry matter were found in each 100 gallons of drainage liquid. The analysis of the dry matter showed it to be composed of 17 to 28 percent of protein, 19 to 23 of ash, 2.3 to 4.3 of lime, 1.3 to 2.2 of phosphoric pentoxide (phosphoric acid), 0.19 to 0.28 of sulfur trioxide, and 0.00 to 2.07 percent of potash. According to this author, drainage causes an appreciable loss of nitrogen and of minerals and hence should be prevented.

As losses from ensiled wet crops are largely due to drainage, it is advisable to ensile crops so that there will be no drainage of juice or, at most, very little. The most favorable dry-matter content in crops to be ensiled is about 30 percent. If more than 70 percent of moisture is found in the crop, it is advisable to allow it to wilt to approximately this moisture content. The drainage juices are composed mostly of organic acids, soluble nitrogenous compounds, potash, calcium, and phosphorus (*1256*).

On the other hand, Blish (*129*) concluded, as a result of his studies with sunflower silage, that the drainage juices (chiefly with young plants) contain relatively little food constituents, being mostly water.

The bottom layers of silage are under a 60- to 100-ton pressure, and this is sufficient to force the flow of juice. The lower 10 feet of the silo may, as a result, be in a waterlogged condition, resulting in considerable spoilage, the silage becoming sour and unpalatable. It would seem therefore that the harm done by retaining the silage juices may be much greater than the small saving that would result from not draining them.

General Comparison of Losses by Different Methods

The losses which silage undergoes depend largely on the method of ensiling. Drew, O'Sullivan, and Deasy (*281*) found 8.4 percent loss of dry matter in a concrete trench silo and 16 to 23 percent in tower silos.

In a study of some 54 silages made from corn and other crops and of the losses of the feed constituents during ensiling, Ragsdale and Turner (*945*) found the following variations in percentages (losses −, gains +): Dry matter, −2.1 to −18.1; protein, +5.1 to −38.4; fat (ether extract), +49.4 to −20.3; ash, +11.7 to −15.7; carbohydrates (nitrogen-free extract), −5.8 to −22.5; crude fiber, +6.7 to −14.6.

Brouwer, De Ruyter de Wildt, and Dijkstra (*158*) (table 20) compared the quality of grass silage made (1) by the A. I. V. process, where 6.2 liters of acid were used per 100 kilograms of fresh grass; (2) with 5.4 liters of 20-percent sugar solution per 100 kilograms of grass, equivalent to 1 percent of sugar; (3) with 2.85 liters of A. I. V. acid containing a small amount of sugar; (4) with nothing added; and (5) by the Holland method (ensiling the partially wilted crop in an open ditch 20 inches deep and covered with soil). They found that the A. I. V. silage was superior to all others in having a higher acidity (less than pH 4.0) and smaller amounts of butyric acid (0.12 to 0.27 percent) and of ammonia nitrogen (16 to 22 percent of the total nitrogen), which indicated that the protein break-down was relatively less in this kind of silage.

TABLE 20.—*Acid, ammonia, dry matter, and protein content of silages made with and without sugar and acid* [1]

Item	A. I. V.	1 percent of sugar added	Some acid, little sugar added	No additions	Holland type
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Lactic acid	0. 7–0. 12	[2] 0. 45 [3] 1. 70	0. 66–1. 05	0. 15–0. 18	0. 10–0. 81
Butyric acid	. 12–. 27	[2] 1. 32 [3] . 13	. 33–. 35	1. 16–1. 50	1. 13–1. 33
Ammonia nitrogen (as percent of total nitrogen)	15. 8–21. 5	21. 4–45. 2	24. 2–33. 2	46. 2–63. 7	49. 6–68. 7
Loss of dry matter	21. 3	13. 1	12. 2	21. 7	14. 4
Loss of crude protein	28. 3	31. 7	25. 4	49. 4	34. 3
Loss of pure protein	40. 0	52. 7	41. 8	61. 1	41. 7
Digestibility coefficient:					
Of crude protein	57. 0				46. 0
Of pure protein	31. 0				19. 0

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[1] The ranges in pH value in each type of silage are: A. I. V., 3.4–4.3; 1 percent of sugar added, 3.8–4.3; some acid, little sugar added, 4.0–4.2; with no additions, 5.0–5.3; and Holland type, 4.7–5.4.

[2] Upper part.

[3] Lower part.

Changes in Acids and Bases

In a study of the changes that take place in the content of acid, volatile bases, and dry matter in crops during the process of making silage, Amos and Woodman (*21*) show the following relative amounts of these constituents before and after ensiling (table 21):

Table 21.—*Comparative content of acids, bases, and dry matter in green crops and in silage*

Constituent	Oats and tares	
	Green	Silage
	Cubic centimeters [1]	*Cubic centimeters* [1]
Volatile organic acids	8	226
Nonvolatile organic acids	285	594
Amino acids	57	400
Volatile bases	18	100
	Kilograms	*Kilograms*
Dry matter	1,000	888

[1] Of normal solution per kilogram used to render neutral

These figures indicate a tremendous increase of volatile acids, an increase of over 100 percent in nonvolatile acids, a sevenfold increase in amino acids, and a fivefold increase in volatile bases (chiefly ammonia), all of which is accompanied by a 12-percent decrease in dry matter.

Composition of Silage and Forage

It is generally admitted that the main use of the silo, especially with grasses and legumes, is to preserve, for future consumption, feeds that, on account of adverse weather conditions, would suffer too great loss of feeding value if field-cured.

Under ideal conditions of field curing the difference in feed value between hay and silage is not appreciable. Carotene, to be sure, undergoes considerable loss in hay that has been field-cured, while in silage it is preserved almost intact. Woll (*1250*) showed that corn fodder, field-cured under normal conditions and then stored over the winter, lost 24 percent of the dry matter and 24 of the protein, whereas the same kind of fodder ensiled lost 16 and 17 percent, respectively. The average losses of dry matter in 54 silos compared to losses from 16 shocks of corn fodder were found to be only 50 percent as great in the silo as in the shocks (*945*).

In a study instituted by Amos and Woodman (*21*) to determine the comparative composition of cured hay and of silage, the results in table 22 were obtained.

Table 22.—*Comparative composition of oat and vetch hay and silage (dry basis)*

Oats and vetch	Protein	Carbohydrates	Oil	Fiber	Ash
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Green	10.8	50.2	3.0	28.1	7.8
Hay	13.9	45.8	2.0	29.0	9.1
Silage	12.5	45.6	[1] 4.3	29.4	8.1

[1] Includes organic acids.

The Kansas Agricultural Experiment Station (*952*) reports the results of a very elaborate study of a number of silages made with alfalfa treated with molasses, or to which corn, soybeans, stover, rye, or combinations of these were added, and compared the composition of these silages when 7 months old with the composition of the green crops when ensiled.

The average composition of the silages and ensiled crops calculated upon the dry-matter basis is as given in table 23.

Comparative analyses of a number of silages and of the ensiled materials are given in table 24, the data having been obtained from different sources. These figures are of interest in showing that the composition of the finished silage approximates that of the fresh material except in the case of carbohydrate (nitrogen-free extract).

TABLE 23.—*Average composition of green crops before and after ensiling*

Feed	Moisture	Ash [1]	Protein [1]	Fiber [1]	Nitrogen-free extract [1]	Fat [1]	Acidity, on fresh basis
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Crops as ensiled	65.1	12.0	15.5	24.1	43.8	4.0	0.4
Silages 7 months old	66.2	13.0	14.8	28.1	40.2	3.9	2.1

[1] Dry basis.

TABLE 24.—*Comparative composition (on dry basis) of various green crops and of silage made therefrom*

Crop or silage	Moisture	Protein (crude)	Ether extract	Fiber (crude)	Ash	Nitrogen-free extract	Kind of silage	Reference
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*		
Grass	80.5	3.0	0.4	5.0	1.7	9.5	A. I. V	(*143*)
Grass silage	79.9	3.1	.6	5.5	1.6	9.3	do	(*143*)
Sunflower	78.6	9.3	1.5	30.3	9.9	49.0	Tower	(*205*)
Sunflower silage	73.8	10.2	2.8	32.6	10.0	44.5	do	
Sunflower, wet by rain	68.2	9.6	2.2	33.3	12.7	42.1	do	(*205*)
Sunflower silage	73.9	8.2	2.1	38.2	15.0	35.6	do	
Corn, milk-stage	75.3	8.4	2.2	20.8	7.6	61.0	do	(*205*)
Corn silage	75.6	10.2	2.7	22.9	7.9	56.4	do	
Corn, glazed-stage	62.9	8.1	2.9	16.8	5.1	67.0	do	(*205*)
Corn silage	69.5	8.3	2.8	22.5	7.1	59.4	do	
Sweetclover, bud stage	65.2	21.2	2.0	29.6	9.2	38.0	do	(*205*)
Sweetclover silage	65.2	21.5	3.3	35.7	9.7	29.8	do	(*205*)
Sweetclover, full bloom	57.2	19.6	2.1	33.5	8.9	35.8	do	(*205*)
Sweetclover silage	67.9	21.4	2.7	32.0	10.0	34.0	do	(*205*)
Fresh vetch fodder	57.7	9.8	3.6	23.5	5.9	54.2	do	(*472*)
Fresh vetch silage	67.2	15.4	3.6	30.2	7.9	41.6	do	
Grass	75.4	10.6	1.5	26.7	8.2	53.0	Concrete trench silo.	(*281, 282*)
Grass silage	75.5	9.2	3.9	39.0	8.2	39.7		
Grass	79.5	12.5	1.6	24.7	8.4	54.9	Tower	(*281, 282*)
Grass silage	75.4	12.5	3.6	31.0	7.6	45.2	do	
Sunflower	81.0	8.4	2.6	27.0	10.0	52.1	do	(*129*)
Sunflower silage	80.8	7.8	3.0	29.7	9.8	49.8	do	

The percentage of ash and fiber especially, and in many cases of fat also, increase somewhat during the ensiling process owing, as has already been stated, to the greater loss in carbohydrate, or nitrogen-free extract.

From data of this kind, however, it is difficult to obtain any real comprehension of the changes that take place during the ensiling process. To do this, the amount of dry matter lost must also be taken into account; that is, the actual weights of the dry matter in both the fresh crops and the silage are the only safe criteria from which losses can be determined.

Feed Values of Hay, Silage, and Fresh Crops

The nutritive value of feeds, fresh, ensiled, or field-cured (see the article, The Nutritive Value of Harvested Forages, p. 956), is dependent on several factors—yield, palatability, composition, digestibility, and physiological effect upon the animal organism.

The coefficient of digestibility of the feed nutrients in the green crop, in silage, and in field-cured hay has been studied by Drew, O'Sullivan, and Deasy (*281*), who found that good silage is little, if at all, inferior to the green crop.

In a recent survey made by the New Jersey and other agricultural experiment stations (*821*), 214 farmers considered grass silage superior to hay, 63 noted no difference between grass silage and hay, while 13 thought the silage inferior. Incidentally, 154 farmers and feeders considered grass silage equal to corn silage for milk production, 116 believed it superior, and 57 inferior.

Experiments with oat and vetch silage indicate that it does not differ materially in composition (on the dry basis) from the hay or the fresh crop (*1256*). In comparing the feed value of silages, it should be remembered that the moisture content plays a large role. If, for example, one silage has 75 percent of water and another 80, then in all feeding tests 50 pounds of the latter must be used to replace 40 of the former.

The role of mineral acids present in fodder on the animal organism has been studied by Crasemann (*239*), who concluded that when silage of the A. I. V. type is fed to animals it produces an acid reaction in the system and an increase in the amount of ammonia and of calcium in the urine; that the feeding of such fodder results in an attack upon the base reserves of the animal tissues; and that such acid-containing feeds should be fed only in connection with high-alkaline hay.

While there is apparently no loss of carotene or vitamin A during ensiling, Watson and Ferguson (*1192*) have concluded that A. I. V. silage is not so efficient as hay artificially dried. Further, while A. I. V. grass silage has about the same feed value as natural-fermentation silage, the latter is more convenient for general use (*281*, *282*).

The opinion of other investigators is that silage prepared with the aid of mineral acids should not be fed too liberally because of possible harmful effect on the animal organism due to the action of the chlorine and sulfuric acid ions. These ions may likewise act injuriously through manure spread upon soils poor in lime, and hence every attempt should be made to replace mineral acids (*414*).

On the other hand, Davies, Botham, and Thompson (*137*) found the loss of starch equivalent by the A. I. V. process to be only 12.8 percent as compared with 24.0 in silage to which molasses was added and 36.2 in ordinary silage. The corresponding losses in digestible crude protein were, respectively, 7.8, 21.1, and 38.2 percent, thus indicating the superiority of A. I. V. silage from this standpoint.

Furthermore, Virtanen (*1169*) showed that the nonprotein nitrogen of A. I. V. silage is made up largely of peptides with little ammonia, whereas ordinary silage contains little peptides and considerable ammonia. Hence the feeding value of nonprotein fractions of A. I. V. silage is superior to that of ordinary silage. It was also shown that the amount of calcium and of phosphorus in the blood of cows that had been fed with A. I. V. silage throughout the winter was normal; that the composition of the teeth and bones of animals fed during a long period was essentially the same as that of animals living on ordinary winter forage; and that though the acidity of the urine increased appreciably, no significant amount of carbonic acid was found. Virtanen fed a limestone mixture containing one-third dehydrated soda in connection with A. I. V. silage and noted that cows consuming as much as 45 pounds daily of this silage mixture gave birth to healthy calves.

NUTRITIVE VALUE OF MISCELLANEOUS FEEDS

by Earl W. McComas and Thompson E. Woodward[1]

THE preceding articles have discussed the nutritive value of growing plants on pasture and range, and of the principal kinds of harvested forage. In addition, there are scores of miscellaneous feeds useful for livestock, including many byproducts from the industries that process human foods. Some are widely, some only locally available. This article considers the more important products, giving brief descriptions and analyses in most cases, and in some cases pointing out precautions that the farmer should keep in mind.

THERE IS an extensive list of feeds for livestock consisting chiefly of byproducts from the milling and processing of foods for human use, and these byproduct feeds are of considerable economic importance. Complete yearly statistics on the volume and value of all byproducts used for livestock feeding are lacking, but the estimate of the Bureau of Agricultural Economics, based on available data, indicates an average annual utilization for the period 1935–38 of the concentrate byproducts, excluding dried skim milk, whey, and buttermilk, of 10,899,000 tons, valued at $305,060,000. These figures do not include any dry roughages such as hulls, stover, or straw, which in the aggregate constitute a very substantial source of energy for particular kinds and classes of animals when fed as part of a complete ration.

This group of miscellaneous feeds includes some concentrates rich in carbohydrates and fat, the chief sources of energy, and others rich in protein, the body-building nutrient. Protein concentrates are widely used to balance rations—which means to increase their efficiency. Included in the concentrates are feeds particularly valuable as sources of minerals and of vitamins. In fact, every known nutritive essential could be furnished by the materials in this group (*819*).[2]

Information on the presence of these essential factors in some of the feedstuffs under discussion is still fragmentary. New facts are constantly being added to knowledge of the properties of these materials. It is the purpose of this article to set forth briefly some of the pertinent facts that are now known.

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[1] Earl W. McComas is Animal Husbandman, Bureau of Animal Industry; and Thompson E. Woodward is Senior Animal Husbandman, Bureau of Dairy Industry.

[2] Italic numbers in parentheses refer to Literature Cited, p. 1075

It should be pointed out here that through the establishment of definitions and standards the Association of American Feed Control Officials has been instrumental in simplifying and unifying the Federal and State feed laws, which cover the composition and labeling of feeds and are designed also to eliminate misrepresentation as to composition. These advances in uniformity make it easier to select the feeds that best serve a particular need and to know the quality of the product offered for sale. For instance, when the term "quality" is used in the name of a feed to denote superior character, as "43-percent protein Cottonseed Meal Prime Quality," the feed must satisfy specific requirements. A product with the same percentage of protein, but below the standard set for prime quality, should be labeled "43-percent protein Cottonseed Meal, Off Quality."

SEEDS, NUTS, AND THEIR BYPRODUCTS

Many of the seeds and seed byproducts are important sources of protein. This is especially true of such oil-bearing seeds as soybeans, which contain nearly 40 percent of protein, cottonseed with over 20 percent, and flaxseed with nearly 25 percent. Though relatively rich in protein and containing fat or carbohydrates in abundance, the nonleguminous seeds are usually deficient in calcium and none too rich in phosphorus. Calcium amounts to less than 0.1 percent of cottonseed and about 0.25 percent of flaxseed. Flaxseed has more phosphorus than the other more common seeds in this group, that element constituting 0.66 percent of the total weight of the seed.

The oilseed byproducts, in the form of meal or cake, contain from 30 to 48 percent of protein. Those with the higher protein percentages are especially valuable as supplements to the common homegrown cereal feeds such as corn, barley, oats, rice, and other carbohydrate concentrates. The process of oil extraction from oil-bearing seeds yields products in the form of cake or meal not only with a higher percentage of protein than was present in the whole seed, but with a higher percentage of mineral matter also. Cottonseed meal, for example, contains a larger proportion of protein than the seed itself, and more phosphorus and calcium as well.

It was formerly believed that cottonseed byproducts caused symptoms of poisoning—blindness and staggering gait—in livestock, due to a toxic substance (gossypol) in the meal, and that therefore they should be fed only in limited quantities and then not over long periods or to young stock. Subsequent investigations showed that similar symptoms were exhibited as a result of vitamin A deficiency. It is now known that this nutritional disorder can be prevented in cattle by supplementing a ration containing cottonseed meal with vitamin A rich materials such as alfalfa-leaf meal, leafy alfalfa hay, silage made from immature crops, or green pasturage. Experimental results by Woodward (*1269*) indicate that young dairy calves under 3 months of age cannot be fed large quantities of cottonseed meal with safety, even when alfalfa hay of good green color is included in the ration. With hogs, however, the problem has been found to be more complicated, although it is recognized that cottonseed meal may be fed to hogs without danger of injuring them if the quantity is limited to 9 percent of the ration. Maynard (*769*) intimates that further disclosures on causes of cottonseed-meal injury may be expected.

Some of the oilseed byproducts offered for sale are pressed into particular shapes, such as cubes or pellets, in order to lessen waste in feeding. To be sold under the label "Prime Quality," they should contain not less than 36 percent of crude protein and meet certain requirements of wholesomeness, etc. When the cake is broken and sorted into various sizes, such as nut, sheep, or pea, it is fed to greater advantage under some conditions. Pea-sized or sheep-sized cakes, for example, are better suited to calf and sheep feeding on the range or pasture when a supplement of this kind is needed.

Meal resulting from the extraction of oil from corn, either by the hydraulic (old) process or the solvent process, is known as corn-oil meal. The protein in the corn-oil meal produced by the old process amounts to nearly 23 percent, about 1 percent less than that in the other, but the digestible nutrients total nearly 79 percent, about 8 percent more. Both products are used in hog and poultry feeding and are considered particularly desirable for poultry.

Soybean-oil meal and cake are becoming available in larger quantities each year. These byproducts contain different percentages of protein, but the highest grade contains as much as 48 percent of protein and about 84 of total digestible nutrients. Oil-extraction processes in which the meal is heated to a rather high temperature yield a product that appears to give better results in hog and poultry feeding than meal not so treated (*209*, *210*), but this is not necessarily true for cattle (*611*) or other classes of stock. Soybean-oil meal has not been experimentally fed as extensively as cottonseed meal, for example, but results so far indicate that it has about the same value as cottonseed meal on a tonnage basis. It appears that there should be further experimentation to determine the relative effectiveness of soybean meal and other more widely used supplements, such as cottonseed meal and linseed meal, in producing fat cattle with a high degree of finish.

Peanuts are rich in oil and contain nearly 25 percent of protein. They are a more desirable feed for cattle or sheep than for hogs, because they tend to produce soft or oily pork. Peanut-oil meal, particularly when produced by the solvent process, is a very desirable protein concentrate, for it is rich in protein and low in fiber, has a high percentage of total digestible nutrients, and is very appetizing.

Some of the seed byproducts on the market contain a relatively low percentage of nutrients and considerable fiber, especially those that are a mixture of meal and hulls. Such materials should bear a distinct name when offered for sale—for example, "cottonseed feed," "oat millfeed," etc.

As used here, the term "miscellaneous feeds" also embraces a number of byproducts suitable for certain classes of animals even though some of the materials contain relatively large percentages of fiber. Hulls from oil-bearing seeds and from other seeds and nuts contain considerable quantities of fiber, yet cattle and other ruminants are equipped by nature to utilize them satisfactorily, provided the rations are otherwise adequate. Some of these low-grade byproducts are important sources of roughage in particular localities. Cottonseed hulls, for example, are much used in the vicinity of cottonseed-oil mills in the Southern and parts of the Southwestern States. Although, as shown in the tables (Composition of the Principal Feedstuffs Used for Livestock, p. 1065), this feeding material contains fully 88 percent as much of total digestible nutrients as red clover hay, it is extremely deficient in vitamin A and low in calcium and phosphorus, all of which are essential to livestock. Peanut hulls have very little feeding value. Their fiber content has been reported to range from 51 to over 71 percent.

Several other seed byproducts deserve mention because of their availability in certain parts of the country.

Coconut (copra) oil cake or meal contains about 21 percent of protein, and when produced by the hydraulic (old) process has a small percentage of phosphorus. It is favored for dairy cattle in the Pacific Coast States because it tends to produce firm butter, and it has given satisfactory results when used in rations for other classes of stock.

Sesame-seed meal, according to Folger (*365*), and sunflower-seed cake, although not marketed extensively in this country, are desirable sources of protein. Meal and cakes from hempseed, from the nuts of several varieties of palms, and from rapeseed and rubber seed, contain varying percentages of protein and other nutrients but are of little importance as feed sources at present. Their composition and digestibility are shown in the tables (pp. 1067–1074).

Straw from legumes harvested for seed, like that from soybeans, alfalfa, peanuts, and various clovers, varies considerably in composition with the kind of legume and also with the proportion of legume plants to others, including weeds, as well as with the extent to which the leaves of the legume have been included. It may be said that the finer the stems of the plant and the higher the proportion of leaves to stems, the greater will be the feeding value of legume straw.

As has been pointed out in the article, The Nutritive Value of Harvested Forages (p. 956), legume hays are rich in protein, but legume straw, as a rule, has very much less protein and is generally comparable with straw from the cereals in total digestible nutrients. Additional protein is therefore usually needed in a ration made up largely of legume straw.

Pea-cannery waste is the green roughage remaining after the peas have been hulled for canning. This product contains a little over 75 percent of moisture, and in this respect may be compared with corn-stover silage. However, it is nearly three times as rich in digestible protein and has about 40 percent more of total digestible nutrients than the stover silage. The cannery waste is often put into the silo for storage, but may be preserved by drying when this can be accomplished with sufficient economy.

Byproducts of the cereal grains and their milling include not only bran, middlings, and shorts, which are used extensively in feeding livestock, but also wheat and corn germ, corn-gluten meal, corn-gluten feed, hominy meal, rice polish, brewers' rice, screenings, and other materials similar in composition and feeding value.

Wheat bran is the coarse outer covering of the wheat kernel as separated from cleaned and scoured wheat in the usual process of commercial milling. It contains nearly 16 percent of protein, a little over 8 of crude fiber, and more than 50 percent of energy-producing nutrients, and is very rich in phosphorus. It is appetizing, and like linseed meal is valued also because it tends to have a laxative effect. Middlings and shorts are somewhat variable in composition, depending on the proportion of bran particles, germ, and fiber, but they contain more total nutrients than bran. Wheat standard middlings, for example, should consist mostly of fine particles of bran and germ and should contain not more than 9.5 percent of crude fiber. Wheat shorts may be termed white, gray, or brown (red), depending on the extent to which fibrous offal from the "tail of the mill" has been included and the percentage of crude fiber. Wheat white shorts, for example, should not contain more than 3.5 percent of crude fiber, whereas the gray may contain 6, and the brown or red up to 7.5 percent.

Corn-germ meal is similar in composition and digestibility to corn-oil meal, mentioned previously. It may consist of corn germ from which part of the oil has been pressed and of other parts of the kernel. Wheat-germ meal usually contains a little more protein than corn-germ meal, and although low in calcium it is rich in phosphorus. Corn-gluten meal is that part of commercial shelled corn that remains after the extraction of the larger part of the starch and germ and the separation of the bran by the process employed in the wet-milling manufacture of cornstarch or corn sirup. Containing over 40 percent of protein and little fiber, it is rich in total digestible nutrients but gives best results when fed with other protein concentrates like soybean meal, which contain proteins not found in the gluten meal. These are especially desirable ingredients in hog, dairy cattle, and poultry rations. Corn-gluten feed is that part of commercial shelled corn that remains after the extraction of the larger part of the starch and germ by the processes employed in the wet-milling manufacture of cornstarch or sirup. Corn-gluten feed, except when standardized to a specific protein content, varies in composition, depending upon the extent to which the corn byproducts, gluten meal, bran, solubles, and corn-oil meal, are included and upon the proportions of these in the product. It is used largely in dairy-cattle rations in combination with other protein-rich feeds.

Brewers' rice consists of broken kernels resulting from the hulling process; it is high in energy-producing material but low in protein. Its total nutritive value approximates that of barley. Experimental work has shown it to be a valuable hog feed, especially as a "hardening" feed to overcome the soft fat produced in hogs fed on peanuts and other feed high in oil. Rice bran consists of the bran layer, together with a small quantity of hull fragments which are unavoidably included in the regular milling of rice. Rice polish is the finely powdered material obtained in polishing the kernel after the hulls and bran have been removed. Rice bran and rice polish contain about 12 percent of protein, but rice polish usually contains somewhat more total digestible nutrients. Rice hulls are not considered desirable feeding material, on account of their flinty nature and their low content of digestible nutrients.

One of the byproducts from the cereal grains, known as screenings, is extremely variable in composition, which depends on the kind and quality of grain from which it is separated, as well as on the kinds and proportion of weed seeds and other foreign material. Grain screenings should not contain more than 14 percent of fiber nor over 6.5 percent of mineral matter. Grain screenings waste, screenings refuse, and scourings are low-grade byproducts obtained in the process of cleaning cereal grains and are of relatively little value as feeds.

Residues from the cereal grains used by brewers and distillers are for the most part dried and sold as brewers' dried grains, distillers' dried grains, distillers' solubles, malt sprouts, etc. Brewers' dried grains are defined as "the dried extracted residue of barley malt alone or in mixture with other cereal grain or grain products resulting from the manufacture of wort" (*43*), the malt infusion used in making beer. They contain about 27 percent of protein and about 7 of fat. Possessing a total of about 66 percent of digestible nutrients, they are comparable to oats, but have less energy-producing nutrients and a little more fiber.

Distillers' dried grains are sold under the name of the grain used or which predominates in a mixture as, for example, "corn distillers' dried grains." The composition of distillers' dried grains varies with the kind or kinds of grain in a mixture. The feed made from corn has about 31 percent of protein, and the total digestible nutrients amount to about 90 percent. The product from rye contains about 25 percent of protein and about 57 of total digestible nutrients, and is much less appetizing.

Malt sprouts obtained as a brewery byproduct from barley are not particularly appetizing, but they have about the same percentage of protein as high-grade brewers' dried grain and about 5 percent more total digestible nutrients.

Dried yeast is of particular value in poultry feeding, not only because it is rich in vitamin G, but also because it is relatively high in protein. The product known as irradiated yeast takes its name from the special treatment applied to strengthen its antirachitic properties.

Other cereal grain byproducts such as straw, corn, or sorghum stover and oat hulls, commonly classified as low-grade roughages, are rather high in fiber and low in protein, and have relatively little of other nutrients. The total of digestible nutrients ranges from about 37 percent in flax straw to about 51 in corn stover. On the whole, these roughages are poor in calcium, phosphorus, and the vitamins. Notwithstanding a considerable variation among the different kinds of straw and the stovers with respect to composition, some of them—oat straw and corn stover, for example—are of considerable value in maintenance rations. However, supplements rich in protein and minerals, and, particularly in the case of young stock, in vitamin A also, must be fed with them for satisfactory results. Wheat and rye straw stems are so stiff and buckwheat straw has so low a content of nutrients that these are less desirable for feeding. Rice straw, with slightly more total digestible nutrients than wheat straw, can be used satisfactorily in maintenance rations when properly supplemented. Barley straw is ordinarily more nutritious than wheat straw, but when the awned varieties are fully matured at the time of harvest the straw may prove to be an unsatisfactory feed, because the awns (beards) may tend to cause sore mouths. In parts of the West, the presence of the weed foxtail (*Hordeum murinum*) in straw may seriously impair its value as a feed.

Well-cured corn stover with most of the leaves present is probably the most valuable of the roughages in this group, for the finer parts are readily eaten when fed to cattle and sheep as the principal part of their wintering ration. The coarse stalks are not eaten to any great extent unless the stover is run through a feed cutter or shredder. When cut or shredded stover is properly supplemented, it has been shown to be about equal to timothy hay for wintering horses.

Refuse from sweet-corn canneries contains about 84 percent of moisture and total digestible nutrients amounting to slightly over 10 percent, including 0.8 percent of digestible protein. Thus it has about the same composition as corn-stover silage and may be ensiled to prevent excessive spoilage if it is to be fed over an extended period.

PRODUCTS FROM ANIMAL AND MARINE SOURCES

Products from animal and marine sources make an important contribution to the total supply of feed nutrients, more particularly protein and minerals. These materials include the edible refuse from meat-packing establishments and fish canneries, as well as the byproducts from creameries and cheese factories. Different drying processes are used in the preparation of protein concentrates such as these. The biological value of the protein is reduced somewhat when the product is dried at high temperatures. For this reason, those products which have not been subjected to very high temperatures are to be preferred when they are to be used for promoting growth or the repair of body tissue.

The product blood meal is 82-percent protein; high-grade digester tankage or meat-meal tankage contains 60 percent of protein and as defined must not contain over 4.37 percent of phosphorus. Tankage produced from animal tissues and bones usually contains more than 4.37 percent of phosphorus and must bear a name indicating its source, such as "digester tankage with bone," or "meat and bonemeal digester tankage." Meat-meal digester tankage, although primarily protein concentrate, is relatively rich in calcium also. These products are used almost entirely and quite effectively in feeding hogs and poultry, but results at several experiment stations indicate that tankage made from meat scraps by the dry-rendering process can be used satisfactorily in rations for cattle and sheep.

Meat-packing byproducts also include bonemeal sold for feeding purposes under such names as "raw bonemeal," "steamed bonemeal," and "special steamed bonemeal." Raw bonemeal should not contain less than 23 percent of protein, whereas steamed bonemeal usually does not have more than half that amount. Bonemeal is important as a source of calcium and phosphorus, being particularly useful as a supplement to pasture and other feeds deficient in these minerals.

Whole milk is recognized as an ideal feed for young animals. Its composition varies somewhat among species and even among breeds, changing also as the lactation period advances. This variation is due largely to differences in the fat content, but to a lesser extent to differences in amounts of lactose, protein, and minerals.

Cow's milk only is available in this country for feeding, but the demand for it for human use, together with the economic and practical problems of transportation and storage, preclude the movement of fresh milk in trade channels for use in feeding livestock.

Dried skim milk is especially desirable in poultry and swine rations and in rations for young calves when it is necessary to raise them without whole milk or fresh skim milk. It contains nearly 85 percent of total digestible nutrients, including about 33 percent of digestible protein, is rich in vitamin G, and approximately half of the mineral matter consists of calcium and phosphorus.

Dried buttermilk is used largely in swine and poultry feeding, but it has been fed satisfactorily to calves. It contains approximately 85 percent of total digestible nutrients and should not have more than 13 percent of minerals, but it should possess at least 5 percent of butterfat. It contains slightly less protein than dried skim milk, but is rich in vitamin G.

Dried whey, a byproduct from cheese making and from processing skim milk to make casein, is especially useful in poultry feeding, largely because of its vitamin G content, but also because it contains about 84 percent of total digestible nutrients. The digestible protein does not exceed 12 percent. This product has proved satisfactory for swine feeding also because of its high digestibility.

Fish meal and fish-residue meal, prepared either from the entire fish or from fish and bone scraps constituting byproducts of canneries, furnish a protein that gives particularly good results when fed to hogs and poultry. However, the nutritive value of fish meal has been found to vary more with the different manufacturing processes than with the variety of fish used. For example, vacuum- and steam-dried meals induced more favorable growth experimentally than the flame-dried meals (*254*). High-grade fish meal may contain as much as 60 percent of protein. A relatively low fat content and low moisture content are preferred because they tend to make the meal less likely to become rancid. Crab and shrimp meals of the best grade are rich in protein, for the former has not less than 25 and the latter over 40 percent, but these should not contain over 3 percent of salt. Properly prepared whale meal is similar to tankage containing about 50 percent of protein.

ROOTS AND UNDERGROUND STEMS

In the group of miscellaneous feeds commonly known as roots and tubers, or underground stems, are the ordinary stock beet, sugar beet, cassava, carrot, chufa, Jerusalem-artichoke, mangel-wurzel, parsnip, potato, sweetpotato, rutabaga or swede, and turnip. Although they contain a high percentage of water, the dry matter in them is highly digestible. Their nutrients are chiefly energy producing, but certain of them are important sources of vitamins. Yellow carrots, for example, are particularly good sources of carotene, a vitamin A precursor, and sweetpotatoes rank next among root crops in this respect. According to J[illegible] (*591*), sweetpotatoes are a good source of vitamin B (old terminology) and contain some vitamin C also. Beet and carrot tops are rich sources of vitamin G. The feeding value of root crops depends to a large extent upon the content of moisture. Sugar beets are more valuable than mangels. From 1 to 2 pounds of feed of this sort may be considered approximately equal to a pound of silage, depending upon the extent to which they are fed, but concentrates should be fed with them in kind and quantity to provide an adequate supply of essential nutrients in the ration. They should always be chopped or sliced when they are fed to animals, but may be fed whole to poultry.

SUPPLEMENTARY FEEDSTUFFS

There are several materials of importance in a consideration of animal feeds, either because they serve to correct deficiencies in many of the staples or are needed to fortify the rations of animals whose particular type of activity makes special demands. These include minerals and feeds containing calcium, phosphorus, iodine, and other nutritive elements required by animals. Browne (*164*), in the 1938 Yearbook of Agriculture, discussed the factors influencing the mineral content of crops, pointing out that crops from soils deficient in certain minerals may themselves be deficient. Statements as to the mineral content of feeds discussed in this article are based on averages of analyses of feeds from all sources, for most of the data were obtained from feedstuffs whose locality of origin was not known.

For example, limestone flour, wood ashes, and oystershell are rich in calcium. Raw bonemeal and steamed bonemeal, bone ash, spent bone black, and dicalcium phosphate supply phosphorus as well as calcium. Iodine is an important mineral supplement under certain circumstances; it is usually supplied in the form of sodium iodide or potassium iodide. However, it should be fed only when needed to prevent goiter, hairlessness, and certain other disorders resulting from iodine deficiency. In many parts of the country the soil is not deficient in iodine, and the livestock produced there seldom, if ever, require an iodine supplement in their rations. Fish meal from marine sources, dried kelp, and cod-liver oil also contain iodine.

Occasionally vitamins must be added to feed combinations when they are deficient in one or more of these substances, or under other specific conditions, as when poultry or other stock are deprived of sunlight, green feeds, or other natural sources of vitamins. A great deal of attention is being given to the study of vitamins and their relation to the welfare of livestock, yet it is admitted that knowledge on this subject is still limited. However, it has been determined that liberal quantities of vitamins A and D especially are required by livestock. It is now recognized that green-colored forage contains carotene, hence bright-green alfalfa-leaf meal, like high-grade hay, is a particularly desirable supplement for correcting vitamin A deficiency. Greenness, however, though a good index of the carotene content of cured herbage, is not necessarily an infallible one. Carotene is only one of several yellow pigments found in foods and feeds.

Fish oils, especially cod-liver oil, are sources of vitamin A and vitamin D as well. Methods for the determination of vitamin A and vitamin D have been refined so that it is possible to determine fairly accurately the content of these nutritive factors in foods and feeds Standards have been established for products intended for animal as well as human consumption. For example, according to a suggested standard, cod-liver oil must contain not less than 600 U. S. P. (U. S. Pharmacopoeia) units of vitamin A, and not less than 85 A. O. A. C. chick units [3] of vitamin D per gram. Dried tomato pomace is rich in vitamin A and has been used satisfactorily as a supplement in dairy cattle and poultry rations. Milk byproducts, such as dried skim milk, dried buttermilk, and dried whey, are rich sources of vitamin G, which appears to be especially needed by poultry for growth. Yeast, which is ordinarily used in the dry form for feeding, also contains vitamin G in abundance.

Wheat germ and wheat-germ oil are sources of vitamin E. Although vitamin E appears necessary for reproduction in the case of poultry, the need of other livestock for this vitamin is open to question. Most feedstuffs contain appreciable amounts of vitamin E, and thus far, no clear-cut conditions have been defined that would warrant the addition of vitamin E-rich supplements expressly for the purpose of correcting reproductive deficiencies in cattle, sheep, goats, horses, mules, or hogs.

Byproducts from the manufacture of sugar from sugar beets and sugarcane are of interest mainly because they are very appetizing and thus tend to induce greater consumption of less attractive feeds when mixed with them. At the same time, they serve as sources of energy, for even the fiber in beet pulp, which amounts to about 19 percent, is highly digestible. Dried beet pulp, molasses beet pulp, beet molasses, sugarcane molasses (blackstrap), and even low-grade sugar are byproducts well suited for use in feeding livestock.

Dried beet pulp contains less than 10 percent of protein but about 70 percent of total digestible nutrients, and it is moderately rich in calcium. Dried molasses beet pulp is only slightly more valuable in terms of total digestible nutrients. These feeds are used to a considerable extent in rations for dairy cattle, and experiments have shown that they may replace a part of the grain in rations for beef cattle, sheep, and horses. Although supporting evidence is not conclusive, experiments at Miles City, Mont., at least suggest that the replacement of a part of the grain by beet pulp in a fattening ration made up of barley and alfalfa hay may reduce the tendency of the steers to bloat.

Molasses may be considered to be about 70 to 80 percent as valuable as corn in a ration, but it is of greatest value when fed in moderate quantities. Both beet and sugarcane molasses contain considerable mineral matter, but that from beets is decidedly deficient in calcium, and cane molasses has only a moderate amount.

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[3] See Practical Nutritive Requirements of Poultry, footnote 9, p. 797

DEFICIENT AND EXCESS MINERALS IN FORAGE IN THE UNITED STATES

by A. M. Hartman [1]

IN various articles in this Yearbook the reader will find references to areas in which there are deficiencies or excesses of certain minerals severe enough to cause trouble with livestock. Where are these areas? A questionnaire was sent to all States to get together whatever definite information there was on this problem, which is a comparatively new one in animal nutrition. Here are the results of the questionnaire. They deal with phosphorus, calcium, iodine, cobalt, copper, iron, fluorine, selenium, and cyanides. Undoubtedly the information is far from complete, but no comprehensive survey of this kind has previously been made.

In many parts of the world, symptoms of malnutrition or disease in livestock on certain areas have been traced to deficiencies of nutritionally essential mineral elements in the available forage. In some of these areas, before the causes of the difficulties were discovered and remedial measures taken, there were serious economic losses as the result of impaired productive capacity and death of animals.

Such deficient areas have been known for some years to exist in the United States, and the question of mineral deficiencies in forages has at one time or another been investigated by many of the State experiment stations. As a result of the cooperative work of several bureaus of this Department and some of the experiment stations, a toxic condition that is sometimes fatal to livestock in certain of the Great Plains and western mountain States has been found to be caused by consumption of native forage (and also grain) containing excessive quantities of selenium.

In order to assemble for the Yearbook information on areas in each State where mineral deficiencies or excesses in the forage have been found to produce symptoms of malnutrition in livestock, a form letter requesting information bearing on this problem was sent to each of the State experiment stations in October 1938. A map of the State was included for indicating affected areas. Replies to these inquiries were received from every State. A number of the States indicated either that no such deficiencies or excesses were known or that no investigations of the question had been made. In addition, there were States in which the reporters intimated that there might be a mineral deficiency of one element or another in relation to animal requirements in the State, either generally or in certain portions. This is true particularly in regard to phosphorus—for example, in a number of States of the Atlantic and Gulf Coastal Plains other than those listed as containing phosphorus-deficient areas. In none of these cases, however, were deficiency symptoms in animals reported. Statements would indicate that surveys of these States should be made before definite conclusions are drawn.

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In fact, there is sufficient evidence in the replies from many States to warrant much more thorough surveys than have yet been made of conditions with regard to various mineral elements. As suggested in the article What Do We Need to Know in Livestock Nutrition? (p. 1045), there is evidently great need for more data and for the compilation, interpretation, and correlation of all data on (1) soil and climatic conditions, (2) mineral content of forage, and (3) animal observations, to determine whether or not optimum conditions for mineral nutrition in the raising of livestock prevail in many range and pasture areas in the United States.

Although it was not specifically requested in the letter, several States reported toxic effects on livestock of mineral matter in drinking water. Only in the case of fluorine have reports of such effects been included in the compilation.

Careful consideration has been given to the information in the replies and on the maps, including publications of the State that were sent with, or cited in, the replies, and in some cases publications of the State that were referred to in those sent or cited. This information served, in the following compilations, as the only source in preparing the abstracts of the listed States; and the only references cited under each State are those mentioned above. In the compilation only those States have been included in which the material indicated that deleterious effects on livestock due to deficiency or excess of a given mineral had been observed. The reporters' own interpretations of conditions in their States have been taken, although in some instances the writer would not agree with them; this is particularly true in regard to calcium deficiencies. Where bone chewing in cattle has been reported, it has been taken as evidence of phosphorus deficiency. Care has been taken not to generalize from too few observations or from observations that may have resulted from purely local farm conditions.

In the abstracts, an attempt has been made to conform to the essentials of the pictures presented in the replies; in some instances material from the publications cited has been added. Where it appeared convenient or expedient to do so, statements in the replies have been quoted verbatim. The maps showing phosphorus and iodine deficiencies (figs. 1 and 2) are based on the maps or the replies from the States.

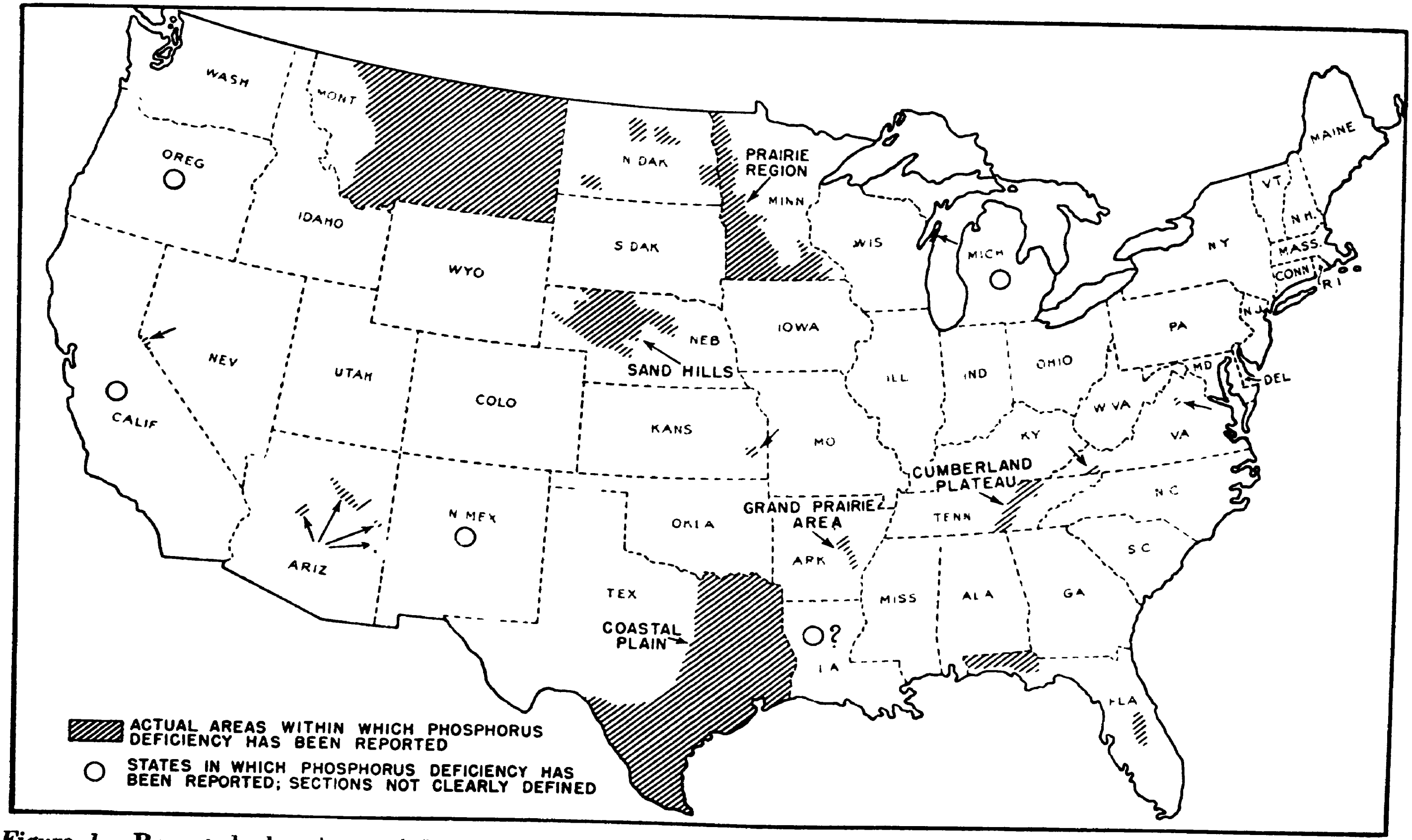
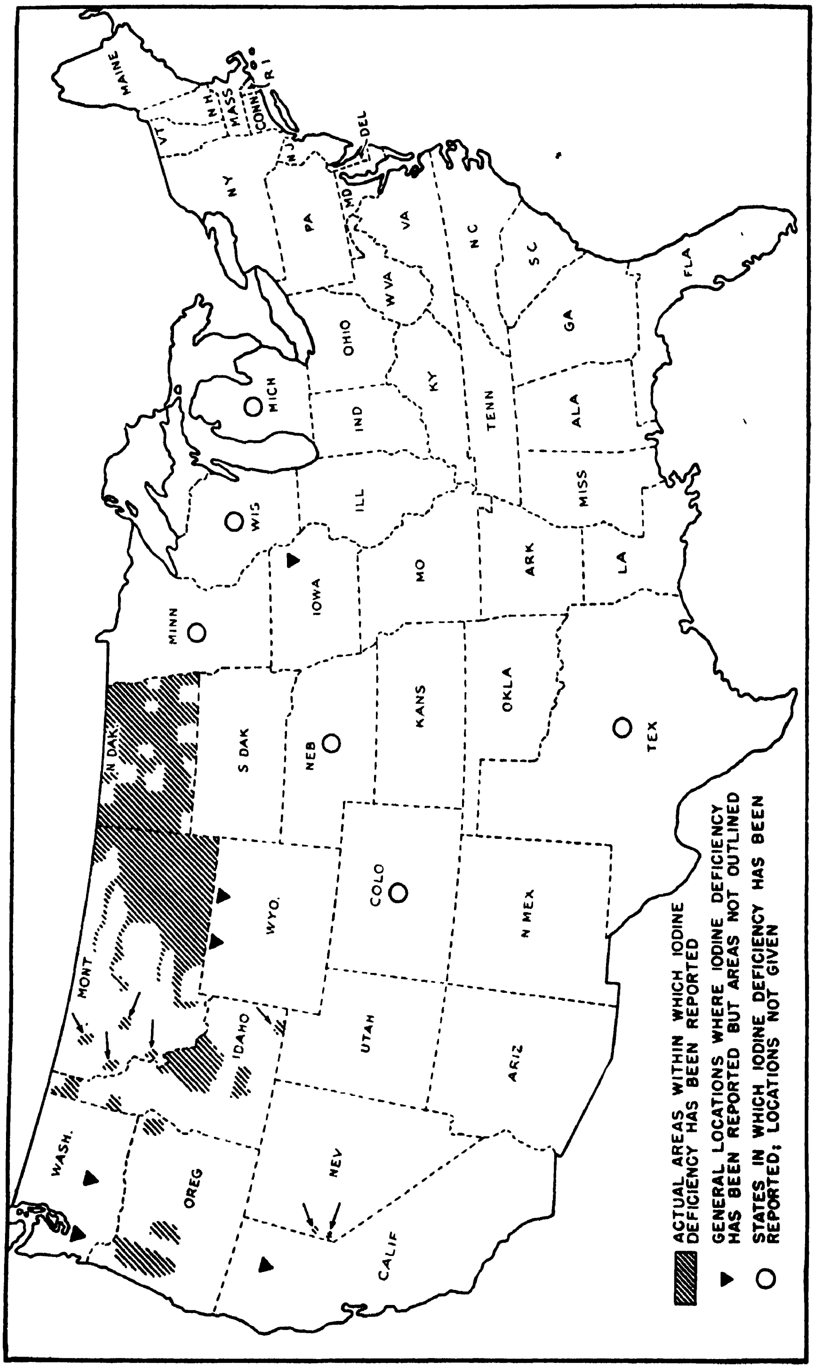


Figure 1.—Reported phosphorus deficiency in the United States. States or areas within which phosphorus-deficiency symptoms in livestock have been reported on maps or in reports submitted by the States. See text for further explanation and for descriptions of conditions in each State.


ACTUAL AREAS WITHIN WHICH IODINE DEFICIENCY HAS BEEN REPORTED
GENERAL LOCATIONS WHERE IODINE DEFICIENCY HAS BEEN REPORTED BUT AREAS NOT OUTLINED
STATES IN WHICH IODINE DEFICIENCY HAS BEEN REPORTED; LOCATIONS NOT GIVEN
MAINE
VT
N H
MASS
CONN
R I
N Y
N J
DEL
PA
MD
VA
W VA
N C
S C
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OHIO
MICH
KY
IND
TENN
ALA
ILL
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WIS
IOWA
MO
ARK
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MINN
KANS
OKLA
TEX
N DAK
S DAK
NEB
COLO
N MEX
MONT
WYO
IDAHO
UTAH
ARIZ
WASH.
OREG
NEV
CALIF

Figure 2.—Reported iodine deficiency in the United States. States, localities, and areas within which symptoms of iodine deficiency in livestock have been reported on maps or in reports submitted by the States. The reports from Iowa and Oregon indicate that there are in those States localities (undesignated), other than those shown, where there is iodine deficiency. See text for further explanation and for descriptions of conditions in each State.

The writer takes this occasion to thank the reporters in every State for their replies.

(Elsewhere in this volume mineral nutrition of various farm animals has been discussed. A review and discussion of excess minerals is contained in the monograph of Mitchell and McClure (*803*).[2] The monograph of Orr and Scherbatoff (*879*) deals with minerals in pastures.)

DEFICIENCIES OF NUTRITIONALLY ESSENTIAL MINERAL ELEMENTS

PHOSPHORUS

Arizona

"We have been working on this problem somewhat over a year and have some analyses of forage and soils from some of the areas where deficiencies have been noted, particularly of phosphorus. * * * While the forages show phosphorus deficiency we have not as yet found blood phosphorus correspondingly low, though in some cases the cattle had shown signs of deficiency some years."

The average phosphorus content of samples of plants from each of several localities ranged from 0.034 to 0.109 percent (basis not stated): one to seven different kinds of plants were represented from each locality. (A.)[3]

Arkansas

There is no region in Arkansas where mineral deficiencies of the forage have actually been demonstrated. However, in a section known as the grand prairie area cattle have been observed eating bones. This area is in the east central part of the State and includes considerable parts of Lonoke, Prairie, and Arkansas Counties, a minor part of White County, and a very small part of Monroe County. Phosphorus deficiencies of the forage are suspected throughout other areas of the State. (B.)

California

"There is a deficiency of certain minerals, particularly phosphorus at certain seasons of the year on our dry foothill ranges due to the fact that the feed dries up and the seeds shatter" (C). This is discussed in California Bulletin 543 (*497*).

In an earlier publication (*495*), Hart and Guilbert reported that mild bone eating had been observed in range herds in several counties of the State.

Florida

"Surveys are not complete but indications based on observation of cattle indicate" at present phosphorus-deficient areas in west and in south central Florida.

"Phosphorus deficient areas in west Florida are high-iron soils. In south central Florida the areas are fine sands. The areas are nearly continuous." [illegible]

Kansas

"There has been no survey of this State to find the sections in which there may be a phosphorus deficiency. I know that there is a phosphorus deficiency in Allen County. * * * I am quite sure that there is a large section in that part of the State where the forage crops during a good portion of the season are deficient in phosphorus content." (H.)

Louisiana

Lush (I) apparently feels that there are phosphorus deficiencies in portions of Louisiana. He submits average values of analyses (air-dried basis) for this element in forage from various areas in the State. The lowest phosphorus figure is 0.097 percent of phosphorus (=0.223 percent of P_2O_5, or phosphorus pentoxide), indicated on a map as being in Allen Parish. Low phosphorus figures also occurred in several other parishes. No statement is made regarding definite phosphorus-deficiency symptoms in livestock in Louisiana, although Lush has written (*700*) of having observed abnormal bone formation in cattle on pasture where the phosphorus in some samples of the forage was rather low.

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[2] Italic numbers in parentheses refer to Literature Cited, p. 1075.

[3] Capital letters in parentheses refer to the individuals in the States, listed at the end of this article (p. 1042), who made the replies. Quoted material is from these replies unless indicated otherwise by reference to Literature Cited.

Lush states in regard to areas which he indicates on his map as being deficient in both calcium and phosphorus:

"We have not determined by feeding experiments or blood analysis that all of these areas are deficient, assuming them to be so because the forage samples were from the better than average farms in the same soil area." (I.)

Literature references sent with or cited in the reply are (*215*), (*700*), and (*701*).

Michigan

"Reports from farmers indicate a rather widespread, though not general, phosphorus deficiency in dairy rations, particularly when the rations consist almost entirely of home-grown feeds. In a few cases, these reports have been investigated and a phosphorus deficiency established. No survey of the State has been made, however, to determine phosphorus deficiency symptoms in dairy herds, hence no areas can be set aside as definitely phosphorus deficient." (K.)

Results of investigations of phosphorus deficiency in dairy cattle in Michigan under field (*553*) and experimental conditions (*552*) have been reported by Huffman and his associates.

Minnesota

The phosphorus deficiency in the native forage in Minnesota and its effect upon cattle have been comprehensively investigated in field and experimental studies. A number of reports dealing with various aspects of the results have been published by Eckles and Palmer and their associates. Reference is made particularly to Minnesota Bulletin 229 (*295*) and Technical Bulletin 91 (*298*). The latter summarizes the results and refers to a number of other papers on the subject by these workers. Further work on the effects of phosphorus deficiency on estrus and reproduction has been reported (*299*).

In 1932 Eckles and his coworkers (*298*) stated that reports indicated that trouble from phosphorus deficiency was more or less prevalent in 30 counties in Minnesota, and in 1938 Clark (L), in his reply to the letter of inquiry, wrote as follows:

"Experimental studies of phosphorus deficient native forage have been under way at the Minnesota Experiment Station for the past 15 years * * *. The location of the phosphorus deficiency in Minnesota is roughly that of the prairie region of the State * * *. All of the prairie is more or less highly calciferous and the available phosphorus in this soil is often quite low. In Traverse and lower Wilkin Counties the till is, in general, lake washed, having been the last bed of old glacier Lake Agassiz which covered the northwest prairie as well as the other northwest counties of the State. The present remainder of this old lake is the Red River, which forms the border of the State from Traverse County north to Canada. It is probable that some of this soil is actually lower than normal in total phosphorus as well as in available phosphorus. Undoubtedly, similar conditions exist on the western side of the Red River, which also forms a part of the old lake.

"Not all of the prairie region of Minnesota has been studied for phosphorus deficiency symptoms in the livestock. The local conditions of feeding are, of course, important contributing factors. Special surveys were conducted in Norman County and in the western prairie section of Mahnomen and Becker Counties in the central northwestern part of the State. Phosphorus deficient cattle were found there. Like conditions were found on farms in Traverse and Big Stone Counties on the central western border and in Renville and Redwood Counties in the central southwestern part of the State. The condition was also identified in the southeastern prairie region of the State. These facts support the conclusion that the basic condition prevails rather generally throughout the prairie region.

"The studies made at the Minnesota station indicate that we are dealing with a permanent natural condition. As evidence may be cited the fact that phosphorus deficient prairie hay which has been purchased for the experimental work at the Central Station has come for many years from the same farm in Mahnomen County."

The average phosphorus content of 51 samples of prairie hay (air-dry basis) grown on the low-phosphorus soils in Minnesota, where phosphorus deficiency occurs among cattle, was 0.106 percent; each sample represented a different farm. Similarly, 5 samples of timothy hay averaged 0.112 percent (*298*).

Montana

"The entire area east of the divide may be considered deficient in phosphorus. In nearly every part of this district, in extremely dry seasons, cattle show the classic symptoms of phosphorus deficiency."

In wet years, with ample green forage, bone chewing and other symptoms are noticeable here in only a few separate sections whose combined area constitutes a minor proportion of the total.

"Throughout the areas of greatest phosphorus deficiency, the use of bonemeal and other phosphatic supplements has been a necessary adjunct to successful stock growing." (M.)

In several publications phosphorus deficiency in livestock (*1203*) and phosphorus analyses of forage crops (*172*, *436*, *437*, *863*, *1018*) in Montana are discussed. (M, M–1.)

Nebraska

In at least most of that area of Nebraska commonly called the sand hills section, the forage is considered deficient enough in phosphorus to affect economy of production and to cause symptoms of malnutrition in livestock when the latter are on unsupplemented winter feed or on range, at any rate in dry seasons. The deficiency is stated to be common enough so that most range men are now feeding a high-phosphorus mineral supplement, with beneficial results.

Phosphorus deficiencies are strongly indicated or suspected in a number of other areas in the State. (N to N–4, inclusive, N 6 to N–9, inclusive.)

Nevada

Based on observation of the situation in regard to mineral deficiencies over a period of approximately 25 years, the following opinion is reported with respect to phosphorus in Nevada:

In a small area, which constitutes a minor portion of Douglas County and borders on the southwest boundary of this county, there has been definite and more or less continuous evidence of phosphorus deficiency, in spite of an abundant food supply in the form of mixed pastures and hay.

"So far as the rest of the State is concerned, we are of the opinion that it is also very much on the border line of phosphorus deficiency and that the feeding of phosphorus supplements is probably warranted on economic grounds—this in spite of the fact that there is only occasionally gross evidence of phosphorus deficiency." (O.)

New Mexico

Phosphorus deficiency in the forage is considered to be the deficiency of greatest concern in New Mexico. Typical symptoms of phosphorus deficiency have been observed in cattle at times.

A phosphorus and calcium survey has been made of the range forages and grasses of the State (*1186*). The first survey was conducted in 1932, a year of normal rainfall, during September and October when the plants were at maturity. On the dry-matter basis the values in a number of areas in widely distributed portions of the State were below 0.113 percent, the approximate danger line for range cattle estimated by Watkins of the State experiment station (*1185*, *1186*). "In many of these low calcium and phosphorus areas that we have located" ranchers have reported inability to raise livestock profitably unless they supply mineral supplements.

"It has been a practice with many successful ranchmen in New Mexico for many years to feed bonemeal to prevent creeps and other troubles originating from lack of calcium and phosphorus in the forage." (P.)

North Dakota

Evidence of phosphorus deficiency in livestock, as judged from chewing of bones and run-down condition, was indicated for a number of counties in North Dakota in replies of county agents to questionnaires, particularly for McHenry, Benson, Hettinger, and Cass Counties. Replies were not received from all counties. Craving of cows for bones, sticks, etc., were recounted in letters received from farmers. "The experience of a number of our stockmen that the feeding of bonemeal has improved the health, reproduction, and milk production of their cows is further evidence indicating a phosphorus deficiency in certain cases. In one of these areas where the feeding of bonemeal proved decidedly beneficial, the prairie hay contained 0.076 percent of P_2O_5 compared to 0.229 percent or more in normal prairie hay."

"On the basis of analyses feed crops may be somewhat deficient in phosphorus. Analyses of alfalfa hay samples from 15 trial plots in the Red River Valley (1929–30) ranged from 0.238 to 0.453 percent of phosphoric acid (P_2O_5), and averaged 0.338 percent (*540*). With the exception of three instances in the first cutting of 1929, application of phosphatic fertilizer caused a material increase in the phosphoric acid content of the hay. This may have been a result of increased leafiness. These percentages, however, tend to range below the generally accepted average of about 0.50 percent for good alfalfa hay." (Q.)

Oregon

"While we do not have enough information to draw accurate regional phosphorus deficiency maps, we do know that we have sections in which phosphorus deficiency symptoms show up in certain years. Wild and grass hays with phosphorus contents around 0.10–0.13 percent are not especially uncommon. We do not, however, have such striking regional deficiencies as, for example, the phosphorus deficient area in western Minnesota.

"We have a considerable amount of analytical information on alfalfa hay. Perhaps one-third of our phosphorus analyses fall under 0.20 percent P. With very few exceptions, cows fed on alfalfa hay show low inorganic blood phosphorus, but we are inclined to attribute this not so much to the low phosphorus content of the hay as to the high Ca/P ratio [ratio of calcium to phosphorus]." (R.)

Tennessee

A continuous area of about 5,000 square miles in one section of Tennessee (the Cumberland Plateau) is designated as producing crops deficient in minerals. "Animals in that area frequently exhibit the well-known symptoms of mineral deficiency such as chewing of wood, bones, and pasteboard boxes. Lespedeza crops grown there are found to carry only one-third to one-half as much P_2O_5 as a similar crop grown in other parts of the State which are well supplied with phosphate. There may be other areas, but we do not have information in regard to them." (T.)

Texas

"We are conducting extensive investigation upon the relation of forage to the composition of the soils in this State. The only deficiency that we have found so far is for phosphorus. This has been demonstrated to occur in Harris County as shown in Texas Bulletin No. 344" (U).

In this bulletin (*1015*) it is reported that bone chewing was observed in about three-fourths of a sizable group of experimental range cattle. Feeding of bonemeal to part of the group cured this habit, prevented "creeps," and enabled cows to rear better calves. It is stated that "creeps" is met with frequently in the Gulf Coast region of Texas and on the more sandy soils in other parts of this State and adjoining States.

"Analysis of forages has shown probability of widespread phosphorus deficiency." From a study of the chemical composition of forage grasses of the East Texas Timber Country, an area of about 26,000,000 acres in the northeastern part of Texas, Fraps and Fudge (*387*) conclude,

"The work indicates a widespread deficiency of phosphoric acid and a possible deficiency of protein in the forage consumed by range animals in the East Texas Timber Country."

It is thought by Fraps (U) that the phosphorus deficiency in forages is probably of extensive occurrence on upland surface soils that contain 0 to 30 parts per million of active phosphoric acid, and that deficiencies probably occur on some soils in areas where the prevailing soils contain 31 to 100 parts per million. (See (*386*), p. 76, for map of active phosphoric acid in soils.)

Virginia

Bone chewing by cattle was reported in a few localities in Virginia (Washington and Madison Counties) in replies to a questionnaire on indication of phosphorus deficiency sent out by the Department of Dairy Husbandry of the Virginia

Agricultural Experiment Station to all county agents and veterinarians in the State. Replies were received from 27 counties (V). Holdaway sums up these replies as follows:

"I do not think that we can consider that any section of the State is seriously affected. It appears that there is some deficiency through the Piedmont region and in the counties immediately east of this region. A few isolated cases in the uplands of southwest Virginia are noted, and one or two of the counties also directly adjacent to Tidewater."

Wisconsin

"We have definite knowledge that phosphorus is deficient in Door County, and there may be other areas in the State where there is a deficiency great enough to cause symptoms of malnutrition in cattle, but we do not have the specific information, except in the case of Door County.

"We appreciate that seasonal conditions have a bearing on any phenomenon such as the mineral deficiency of forages * * *." (Y.)

Results of investigations of phosphorus deficiency disease in parts of this State have been published by Hart and his associates in Wisconsin Bulletin 389 (*485*). Samples of sweetclover hay from the affected area ranged from 0.200 to 0.267 percent in P_2O_5 content; the single value for alfalfa hay was 0.328 percent.

CALCIUM

Florida

Surveys of Florida are not complete.

"Dairy cattle grazed on the cobalt-deficient areas without the use of a calcium supplement suffer from calcium deficiency" (E). (See Florida under Cobalt.)

Louisiana

Lush (I) apparently feels that there is calcium deficiency in portions of Louisiana. He submits and refers to average values of analyses for this element in forage from various areas in the State. However, the forage appears from the average figures given to be higher in calcium than has been found in numerous instances to be adequate. The lowest figure given is apparently 0.202 percent of calcium (=0.283 percent of calcium oxide) in air-dried material. On the map submitted by Lush this is shown as being in Livingston Parish. The figures submitted for the rest of the State were much above this value. (See this State under Phosphorus.)

Nebraska

It is reported that calcium deficiencies occur on quite a number of farms—some areas in Nebraska and are manifested by depraved appetites in cattle, horses, and sheep. It is stated that this condition seems to be corrected by feeding a calcium supplement. (N-7.)

Virginia

It is reported (V) that incidental to his reply to the phosphorus-deficiency questionnaire (see Virginia under Phosphorus), the agent of Lunenburg County, Va., reported some trouble with dairy cattle and hogs that was diagnosed by veterinarians as calcium deficiency.

West Virginia

"* * * We have in recent years had called to our attention, in a few sections [of West Virginia], conditions of young horses which were apparently due to a lack of calcium in that particular region. Upon changing the roughage used to a good alfalfa hay and in a few cases recommending feeding of minerals, these colts have, over a long period, improved, which would lead us to believe that our diagnosis of the trouble was correct." (X.)

IODINE

California

Hart (C) reports on the situation in California as follows:

"In California we have a definite iodine deficiency in all forms of livestock along Hat Creek in Shasta County up to the point where it becomes confluent with Rising River. There is no iodine deficiency along Rising River or below where it joins Hat Creek.

"This area is the most definitely iodine deficient area that we have found. However, there have been isolated cases of dead young animals with swollen throats reported in the lava bed areas in Modoc and Lassen Counties, but we have not followed them up.

"The fact that Rising River showed no cases while Hat Creek has such a serious deficiency until it becomes confluent with Rising River was very interesting. Since we have the livestock men educated to the proper use of iodine along Hat Creek no difficulty has been experienced."

Colorado

It is reported that while there are indications of iodine deficiency in Colorado, "they are not sufficiently great nor sufficiently localized to point to any locations of aggravated deficiency." (D.)

Idaho

The entire State of Idaho is stated to be on the border line of being iodine deficient. Counties in which iodine deficiency among livestock has occurred have been indicated as Franklin, Gooding, Lincoln, Custer, Lemhi, Latah, and Bonner.

"* * * I believe that iodine is about the only mineral in Idaho that is deficient in the natural feeds produced. We have an area around Salmon and Challis, Idaho, where we have had considerable trouble with hairlessness in pigs and big neck in calves. The feeding of iodine supplements has in all cases cured this nutritional deficiency, which points definitely to the lack of iodine." (F.)

Iowa

"* * * it has been noted that goitre conditions are more prevalent in lambs and calves in northeastern Iowa than in other sections of the State.

"No data are available that make it possible to fix the limits of this area."

Good results from feeding iodine in some experiments at the Iowa station (*352*, *354*) "might be interpreted as suggesting an iodine deficiency in Iowa rations or water." (G.)

Michigan

"A deficiency of iodine as indicated by a prevalence of goiter is also rather widespread in Michigan. The situation is * * * not general, as the disease may be found in the cattle on one farm but not on an adjoining farm. Undoubtedly, feeding practices are a determining factor in iodine deficiency on Michigan farms.

"Dr. Kimball (*627*) made a study of the iodine content of Michigan waters and reports as follows: No iodine found in samples from northern counties; 0.5 p. p. b. [parts per billion] of iodine in samples from central counties; 7.3 p. p. b. of iodine in waters from south central counties; 8.7 p. p. b. of iodine in samples of water from southern counties." (K.)

Minnesota

"Mention should be made of the fact that iodine deficiency is undoubtedly prevalent in many spots in the State of Minnesota. Whether forage, grain, or water supplies are chiefly responsible has not been determined. No survey of the incidence of iodine deficiency in the State has been made and we have, as yet, made no chemical studies of the iodine content of the crops grown in various sections of the State." (L.)

Montana

As determined by the presence of goiter, roughly one-third to one-half of the area of Montana is indicated as iodine deficient. This area is nearly continuous and is situated principally in the eastern, southeastern, and central-southern parts of the State. There are a few very small scattered areas west of the Divide.

"Throughout these areas, and especially in central-eastern Montana, newborn livestock of all types are likely to be affected with goiter. The use of iodized stock salt has completely controlled losses from this source. Areas of iodine deficiency can be much more sharply defined than those of phosphorus deficiency as climatic conditions seem to have no relation to goiter occurrence." (M.)

Several Montana publications (*1201*, *1202*, *1204*) are referred to as dealing with iodine deficiency in farm animals.

Nebraska

It is reported that there is occasional evidence of goiter in dairy calves in Nebraska. (N-4.)

Nevada

Based on observation for approximately 25 years of the situation in Nevada in regard to mineral deficiencies, the following opinion is reported with regard to iodine:

There is definite evidence of iodine deficiency as manifested by occasional goitrous calves in two very small areas—one in the southern part of Washoe County and one in the western part of Ormsby County.

"This manifestation of iodine deficiency has, however, been periodic rather than continuous, and it has not been a problem of much practical importance. It is our opinion, though based largely on geologic observations and analogy, that all of this State is probably a border-line iodine deficiency area. The fact that our livestock have not shown more gross evidence of this may well be due to the widespread use of iodized salt for stock salting purposes." (O.)

North Dakota

Reports from various parts of North Dakota indicate that the occurrence of hairlessness in pigs and goiter in farm animals is sufficiently widespread to justify the feeding of iodine as a general practice. (Q) (*206*).

"In North Dakota the birth of hairless pigs is more common than the birth of calves or lambs with 'big neck,' or the birth of weak, goitered foals. In general, the frequency and severity of the occurrence in the State increases from east to west. In the eastern part of the State hairless litters may occur only once in 4 or 5 years; whereas, in the western part, hairless litters occur every year, and the goiter in other farm animals is also more prevalent. Goiter appears to be more prevalent after long, cold winters" (*206*).

Iodine deficiency in farm animals in North Dakota is discussed in publications (*206*) and (*1040*). The latter contains a map showing the occurrence of litters of hairless pigs in various years, as reported by county agents: some counties do not, however, have agents. The information on this map was presented on the map submitted with the reply from North Dakota and has been incorporated into the United States map showing iodine deficiency in livestock (fig. 2, p. 1030).

Oregon

Regarding the incidence in Oregon of goiter in livestock, it is stated, "While goiter is found over widely scattered areas, there are, however, a number of approximately defined regions in which goiter occurs much more frequently." The center of most severe goiter occurrence is indicated as an area consisting roughly of the northwest half of Deschutes County and the adjoining southwest one-third to one-half of Jefferson County, and is bordered by areas of less severe occurrence. "Parts of the upper Deschutes basin can undoubtedly be classed as severely goitrous." There is a considerable area, not sharply defined or thickly settled, in Wallowa County, chiefly in the southwest half. A third area, varying from border-line to moderately severe, is indicated in the western part of the State: it is composed roughly of the western halves of Multnomah, Clackamas, Marion, and Linn Counties, the central third of Lane County, practically all of Benton County, and the eastern halves of Polk and Yamhill Counties.

In the goitrous sections, the use of iodine medication has greatly reduced the losses from this deficiency.

The following iodine analyses and comments on livestock relative to them are given:

"Drinking water of glacial origin (Mount Hood) contains 0.1 p. p. b. or less of iodine. Corvallis city water (mountain springs and small streams) contains some 0.3 p. p. b. of iodine. Local valley streams (ground water) contain some 1.5 p. p. b. of iodine. Local hays (slightly goitrous area) contain some 75 to 100 p. p. b. of iodine. A sample of alfalfa hay from a very goitrous area contained 45 p. p. b. Local barley contains 3 p. p. b. or less of iodine. Barn-fed animals on local feedstuffs and Corvallis city water are goïtrous. Animals on local pastures and local valley streams are borderline with respect to goiter.

"On the college farm, using Corvallis city water, goiter in barn-fed animals is sufficiently severe so that when the use of iodine is discontinued for some 3 to 6 months, goiter is observed in the newborn. This is especially true of horses." (R.)

Texas

No extensive study has been made of the iodine problem in Texas; however, there are as yet no indications of any serious deficiency of this element (U). Schmidt (*1015*) states that in Texas as a rule the animal finds enough iodine available in the food it consumes, though some regions are known where this is not the case.

Washington

"Sufficient work has been done in the field of investigating iodine deficiency that we know definitely that this exists in the State of Washington. Our so-called goitrous belt, although it has not been carefully charted, is confined largely to the eastern slope of the Cascade Mountains along the valleys of the Columbia River and its tributaries, and the condition is evident by simple goiter occurring in newborn domestic animals, particularly goats, sheep, hogs, cattle, and horses * * * . There is also evident a lesser degree of iodine deficiency on the western slope of the Cascade Mountains. Since the almost universal use of iodine, or its salts, in the treatment of pregnant females in domestic animals, very little simple goiter is observable in these goitrous areas." (W.)

This subject has been discussed by Kalkus in Washington Agricultural Experiment Station Bulletin 156 (*605*) (W-1).

Wisconsin

Wisconsin reports "iodine deficiency at times experienced in various parts of Wisconsin." "We have noted at times that a long, hard winter has accentuated trouble from the iodine deficiencies in livestock." (Y.)

Iodine deficiencies have been reported by Hart and Steenbock in Wisconsin Bulletin 297 (*491*).

Wyoming

There is a reported iodine deficiency in certain areas in northern Wyoming, particularly in the northeast region of Park County, in the northwest region of Big Horn County, and in the northern part of Sheridan County. No research has been done to establish the boundaries of this area. The general picture is formed merely from reports of goiter in lambs and a few hairless pigs, conditions which seem to be eliminated by feeding iodized mineral. (Z.)

COBALT

Florida

"Surveys are not complete but indications based on observation of cattle indicate" at the present time a considerable cobalt-deficient area in Florida, more or less continuous in extent, encompassing roughly the northern, central, and south-central parts of the State and restricted areas along the northern Gulf coast.

In commenting upon this, it is stated: "Cobalt deficient soils include the lighter sandy soils, very few of which are low-lying. The proportion of definitely affected land will vary from 10 to 75 percent" in the area. "Adjacent ranges may be deficient or healthy." (E.)

Massachusetts

(See under Iron.)

COPPER

Florida

"Surveys are not complete but indications based on observation of cattle indicate" at present a few restricted copper-deficient areas in north and south central Florida. In regard to this, it is stated, "Copper deficient soils include many of those high in organic matter, and in addition certain other sandy soils." (E.)

IRON

Massachusetts

"There is only one region of rather limited area in our State [Massachusetts] where a specific mineral deficiency has been demonstrated. As indicated roughly * * * this area is confined to the coastal region around Buzzards Bay, Vineyard Sound, and portions of Cape Cod Bay." While this area represents sections where cases of this mineral deficiency in cattle have actually been located, it is thought probable that the deficiency occurs through the whole coastal region in the southeastern section of the State.

"This deficiency, we believe to be of iron but some more recent work at the Wisconsin station and in Australia and New Zealand suggests it may possibly be cobalt." (J.)

Results of investigation of this deficiency in cattle have been reported by Archibald and his associates (*29*).

EXCESS MINERALS

FLUORINE

Arkansas

A small continuous area in the central part of Arkansas is indicated as a bauxite-producing section. (This area encompasses small portions each of Pulaski, Saline, and Grant Counties, located respectively in the southwestern, southeastern, and northeastern parts of these counties.)

"We have considerable evidence which leads us to believe that there is an excess of fluorine in feeds produced in this area." (B.)

California

Although drinking water was not mentioned in the form letter of inquiry sent to the States, California reported as follows:

"We * * * have found small quantities of fluorine in certain warm springs in Modoc County which has been present in sufficient quantities to cause trouble with the teeth of cattle." (C.)

Other Reports

A very few other States reported that while in some localities there were quantities of fluorine in the drinking water sufficient to cause mottled teeth among the human population, no injurious effects on livestock from this element were known in these localities. (See the section on Fluorine in the article Mineral Needs of Man, p. 187.)

SELENIUM

Nebraska

"So far as I am aware, the only areas of Nebraska in which selenium is sufficiently abundant to be toxic to animals (fig. 3) include some of the soils developing from Cretaceous formations—Pierre shale and Niobrara chalk—in Boyd, Keyapaha, and Knox Counties. The most troublesome area is in the vicinity of Lynch, Nebr." (N-5.)

South Dakota

The situation in South Dakota is indicated by the map (fig. 4) and the statement accompanying it, both of which were submitted by I. B. Johnson (S).

Wyoming

Survey of Wyoming to determine the location of selenium in quantities large enough to cause damage to livestock has not been completed.

The places indicated on the map (fig. 5) represent "various localities and counties where selenium has been found in forage, and where there seems to be definite injury to animals caused by it." (Z.)

Occurrence of selenium and seleniferous vegetation in the State are discussed in Wyoming Bulletin 221 (*74*, *639*).

Statement on Effects on Livestock of Selenium in Forage

In addition, several States referred to H. G. Byers and his associates in the Bureau of Plant Industry of this Department and to their extensive work on surveys of selenium in soils and related topics (*181*, *182*, *183*, *1226*) for information concerning the relation of selenium in forage to harmful effects on livestock. Dr. Byers was therefore requested to make a general statement concerning the relation of selenium in soils and plants to resulting animal injury. This he kindly consented to do. His statement follows:

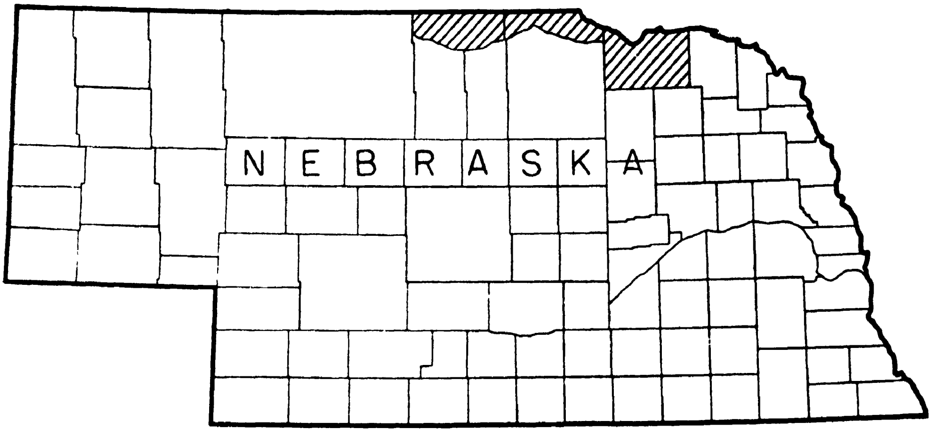

Figure 3.—Reported occurrence of selenium poisoning in Nebraska. Within the shaded counties (Keyapha, Boyd, and Knox) localities are reported in which selenium is sufficiently abundant to be toxic to animals. See text for further explanation. (Map prepared from data submitted by F. A. Hayes (N–5).)

"It has been abundantly demonstrated that there are numerous areas in certain of the Great Plains and Mountain States which produce seleniferous vegetation. The term 'seleniferous vegetation' is to be understood as referring to plants containing sufficient selenium so that if eaten in adequate quantities by animals definite physiological disturbance follows.

"For the most part highly seleniferous vegetation consists of plant species not normally consumed by animals. When normal forage or food crops are toxic by reason of selenium, there is a wide variation in toxicity between different plant species grown under essentially identical conditions and between different samples of the same materials grown at different points within limited areas. Even in the areas most severely affected it appears that by no means all the vegetation is poisonous. The concentration of selenium in a given plant also varies seasonally.

"Because of variables of the type mentioned, and because animals native to a region learn to avoid highly toxic vegetation except when driven by hunger, animal injury is of variable intensity even in narrowly restricted areas. The field workers on the occurrence and distribution of selenium have observed many cases of 'alkali disease' (selenium poisoning), but only in a few cases have competent post mortem or other examinations definitely established the cause of the injury. No real effort has as yet been made to evaluate the extent of animal injury due to selenium. It does not appear possible to definitely delimit on maps those areas in which selenium poisoning is a serious problem. Selenium appears to be present to some extent in all plants and is therefore, of necessity, a factor in the animal diet. It is definitely injurious to animals when ingested in sufficient quantity. Whether in sufficiently minute quantities it may be considered as an essential element in either plant or animal nutrition is not known."

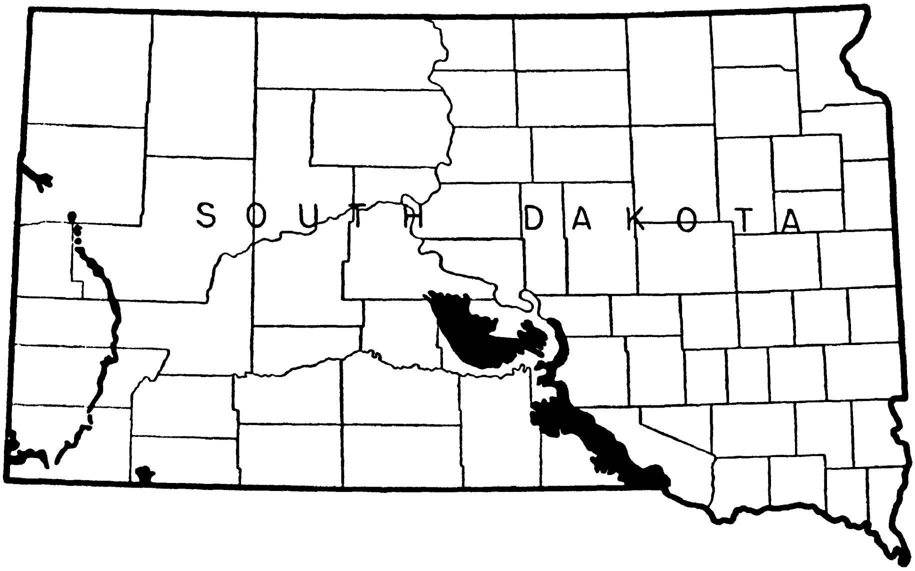

Figure 4.—Reported occurrence of selenium poisoning in South Dakota. The black area is, generally speaking, the most seleniferous part of South Dakota. Within this area are included the majority of the farms or ranches where selenium poisoning is a major problem. Because the map is generalized, it may give the impression that all of the black area is seleniferous and that all farmers or ranchers within the area suffer losses from selenium poisoning. Such is not the case. Much of the land included in this area does not produce seleniferous vegetation, and many of the farmers have suffered no losses from the disease. However, within this area, selenium poisoning constitutes a greater problem than it does in any other similar area in the State. Cases of selenium poisoning may be found in the western part of the State outside of this area. However, these cases are scattered and usually less severe, and losses constitute less of a problem than they do in the black area. The boundaries of the black area were made on the basis of geological, soil, and plant data, and the actual occurrence of the disease, as reported since the beginning of the project. In some parts they may indicate an exact boundary between seleniferous and nonseleniferous land, but for the most part they indicate a transition zone. (Map and legend submitted by I. B. Johnson (S).)

CYANIDES [4]

Colorado

In the reply from Colorado, the following statement was included:

"Toxic alkaloids, glycosides, and cyanides in range plants account each year for appreciable losses of livestock in this State." (D.)

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[4] The writer in classing cyanides as minerals realizes that the classification is questionable in this case.

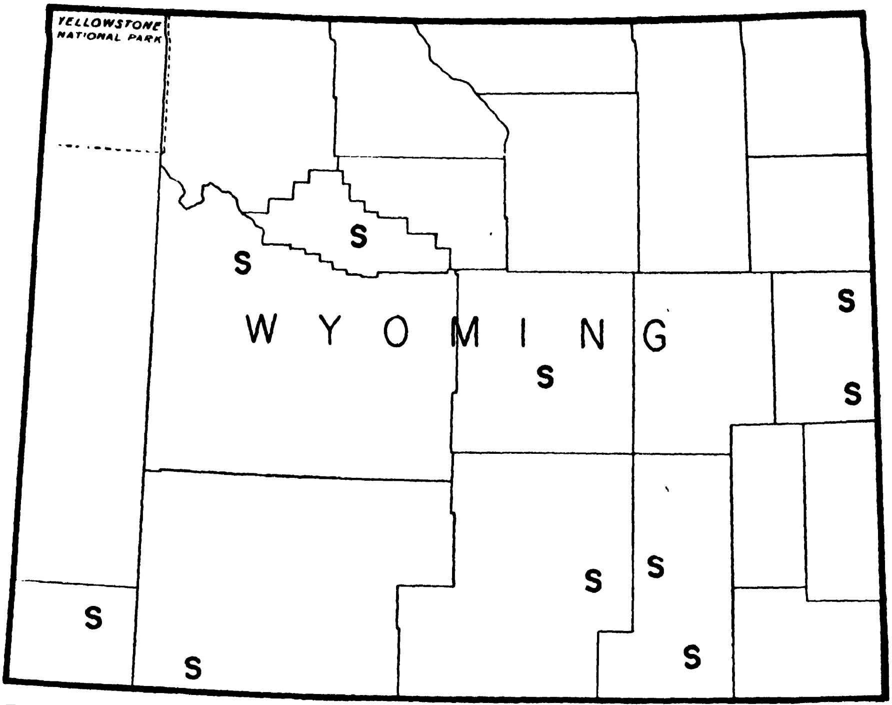

Figure 5.—Reported occurrence of selenium poisoning in Wyoming. "S" indicates general localities where selenium injury to livestock has been reported. (Map submitted by J. A. Hill (Z).)

KEY LIST OF INDIVIDUALS REPLYING TO LETTER OF INQUIRY

(A) Arizona.

A. H. Walker, assistant animal husbandman, Agricultural Experiment Station, Tucson.

(B) Arkansas.

W. R. Horlacher, head of animal industry department, Agricultural Experiment Station, Fayetteville.

(C) California.

George H. Hart, head of animal industry division, Agricultural Experiment Station, Davis.

(D) Colorado.

J. W. Tobiska, head of chemistry research department, Agricultural Experiment Station, Fort Collins.

(E) Florida.

Wilmon Newell, director, Agricultural Experiment Station, Gainesville. (Conference held with members of staff.)

(F) Idaho.

W. M. Beeson, associate professor of animal husbandry, College of Agriculture, University of Idaho, Moscow.

(G) Iowa.

W. H. Stevenson, vice director, Agricultural Experiment Station, Ames. (Transmitted report of a station committee, members not named.)

(H) Kansas.

J. S. Hughes, professor of chemistry, and animal nutritionist, Agricultural Experiment Station, Manhattan.

(I) Louisiana.

R. H. Lush, dairy husbandman in charge of dairy research, Agricultural Experiment Station, University.

(J) Massachusetts.

J. G. Archibald, research professor of animal husbandry, Agricultural Experiment Station, Amherst.

(K) Michigan.

C. E. Millar, head of soils department, Agricultural Experiment Station, East Lansing. (Conferred with C. F. Huffman, research associate in dairy husbandry.)

(L) Minnesota.

W. C. Coffey, director, Agricultural Experiment Station, University Farm, St. Paul.

(M) Montana.

H. Welch, research veterinarian, Agricultural Experiment Station, Bozeman.

(M–1) Edmund Burke, head of chemistry department, Agricultural Experiment Station, Bozeman.

(N) Nebraska.

Wm. J. Loeffel, acting chairman, animal husbandry department, Agricultural Experiment Station, Lincoln. Professor Loeffel conferred with the members of the staff and quoted statements from the following in his reply:

(N–1) C. W. Ackerson, associate professor and assistant agricultural chemist;
(N–2) M. L. Baker, animal husbandman, North Platte substation;
(N–3) E. M. Brouse, superintendent, Valentine substation;
(N–4) H. P. Davis, professor and chairman of dairy husbandry department;
(N–5) F. A. Hayes, professor of soil science, cooperating with the United States Department of Agriculture;
(N–6) F. E. Mussehl, professor and chairman of poultry husbandry department;
(N–7) R. R. Thalman, associate professor, in charge beef cattle investigations;
(N–8) L. Van Es, professor and chairman of animal pathology and hygiene department;
(N–9) M. D. Weldon, associate professor, in charge soils research.

(O) Nevada.

Edward Records, head of department of veterinary science, Agricultural Experiment Station, Reno.

(P) New Mexico.

W. E. Watkins, nutrition chemist and associate in animal husbandry, Agricultural Experiment Station, State College.

(Q) North Dakota.

F. W. Christensen, professor and chairman of department of animal and human nutrition, Agricultural Experiment Station, State College Station, Fargo. (Transmitted a typewritten report, "The Phosphate Situation in North Dakota," by T. H. Hopper, F. W. Christensen, and T. E. Stoa, all of the North Dakota station, from which quoted matter and some of the statements in the text were taken.)

(R) Oregon.

J. R. Haag, nutrition chemist, Agricultural Experiment Station, Corvallis.

(S) South Dakota.

I. B. Johnson, director, Agricultural Experiment Station, Brookings.

(T) Tennessee.

C. A. Mooers, director, Agricultural Experiment Station, Knoxville.

(U) Texas.

G. S. Fraps, chief of chemistry division and State chemist, Agricultural Experiment Station, College Station.

(V) Virginia.

C. W. Holdaway, head, department of dairy husbandry, Agricultural Experiment Station, Blacksburg.

(W) Washington.

J. W. Kalkus, superintendent, Western Washington Agricultural Experiment Station, Puyallup.

(W–1) J. C. Knott, associate professor, department of dairy husbandry, State College of Washington, Pullman.

(X) West Virginia.
  E. A. Livesay, head of animal husbandry department, Agricultural Experiment Station, Morgantown.
(Y) Wisconsin.
  Noble Clark, associate director, Agricultural Experiment Station, Madison.
(Z) Wyoming.
  J. A. Hill, director, Agricultural Experiment Station, Laramie.

WHAT DO WE NEED TO KNOW IN LIVESTOCK NUTRITION?

by O. E. Reed [1]

THROUGHOUT the United States there are scores of workers in the State experiment stations and the Department of Agriculture investigating problems in animal nutrition. What do these workers think are the important unsolved problems at the present time? What do they think needs to be known about nutrition in order that livestock and livestock products may be produced more efficiently by farmers in the United States? What do they believe are some of the important trends today in animal feeding? Here, in not too technical language, you will find frank answers to these questions by the workers themselves, including many who are famous in their various fields.

WHEN I was asked to write on this topic for the Yearbook, it occurred to me that a discussion by leaders in livestock nutrition would be most helpful and suggestive to those planning work in this field. The following letter was therefore addressed to the directors of the State agricultural experiment stations, and in some cases to members of their staffs:

> As you may know, the Yearbook of the United States Department of Agriculture this year is to be devoted to papers on various subjects in animal nutrition—human and livestock. In the part on the nutrition of livestock there is planned a paper expanding the following theme: Incomplete knowledge of nutritional requirements of farm animals and the nutritive value of foods on the part of the farmer does not enable him to plan his feeding program most effectively.
>
> In this paper it is planned to consider the problems in livestock nutrition upon which information is most needed and where further information, if it were at hand, would contribute most to the economic welfare of the farmer. * * *
>
> Because of your broad experience and the thought that you have given to work of this sort for years, we would appreciate very much having your judgment on this question and knowing from you what problems in livestock nutrition and feeding you would now put uppermost in your mind.

Some of the responses received were from committees or individual workers appointed by the directors. This article is devoted almost exclusively to the presentation of these replies. In fact I have tried to turn the program over to my correspondents. It is impossible to present all of the replies in full; but as far as possible where this has not been done, I have selected excerpts from these replies to represent the views expressed in them. The same problem has frequently been suggested repeatedly in different replies. I have not hesitated to repeat these suggestions, the purpose of this survey being not to determine what unsolved problems exist in livestock nutrition, but rather to determine the relative importance of these problems in the opinion of leaders in this field.

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[1] O. E. Reed is Chief of the Bureau of Dairy Industry.

The topic may be considered from two standpoints: (1) The gaps in existing knowledge of the nutritional requirements of farm animals and the nutritional value of feeds, and (2) existing knowledge with which the farmer is not familiar and which would be of practical help to him. A number of replies consider both aspects of the problem; most of them, however, are devoted mainly to the lines of investigation which the authors feel would contribute most to the economic welfare of the farmer. Some include very complete and very carefully prepared research programs.

THE BROAD VIEW

Some of the replies to my letter take a broad general view of the field of research in animal nutrition. The reply of Dr. James T. Jardine, Chief of the Office of Experiment Stations, United States Department of Agriculture, which I quote in part, is of interest in this connection:

> Looking at this problem from a broad viewpoint, there are two major aspects that appear to be vital to the development of this field of research. These are: (1) The relation of nutrition to the physiological processes of the various classes of livestock, and (2) the relation of deficiencies or excesses of feed constituents to diseases and disorders of livestock.
>
> The first of these problems can be broken down into a number of definite phases that will indicate the type of desirable research. For example, there is a definite need for information regarding the effect of the various vitamin, mineral, and other constituents of feeds upon the secretion of fluids by the various endocrine glands of the body, which in turn influence such physiological processes as lactation, reproduction, growth, etc. The second major problem includes such important lines of work as the effect of selenium on livestock, the disorders occurring as a result of deficiencies in cobalt and phosphorus on the mineral side, and of all the vitamins on the biological side. There is a big gap in our knowledge of the interrelationship of feed intake and the functioning of the animal organism. There is also the broad problem of the effect of soils, climate, and other factors upon the nutritive value of the feeds ingested by livestock.
>
> Certain broad principles relating to the basic knowledge of animal nutrition can be developed in laboratories, but these principles must be tested for national, regional, and local adaptation by workers located in varying sections of the country.
>
> I trust that these ideas, advanced from such a broad outlook, may be of assistance to the Committee preparing the material for the animal nutrition section of the Yearbook.

The following comprehensive statement of the objectives of research in animal nutrition from E. B. Hart, chairman of the department of biochemistry, Wisconsin Agricultural Experiment Station, and for about 33 years professor at the University of Wisconsin, is of particular interest considering the wide range of valuable contributions that the Wisconsin laboratory, under his direction, has made in the field of nutrition:

> In my judgment one can divide the problems of animal nutrition into two classes: (1) Those of a fundamental character and applicable to all classes of livestock the world over, and (2) the more local practical problems of animal feeding.
>
> Under the first, of course, my notion is that we should catalogue all the factors involved in the nutrition of animals, learn how to assay for these factors in our foodstuffs, and then in addition determine the needs of these factors quantitatively for livestock. That is a big problem, but it is the ultimate goal of any program for the development of fundamental knowledge of nutrition.
>
> Under the second heading of local problems, I can only speak for the situation in Wisconsin. Here we need to know (1) how best to preserve the green crop and look forward to whether such preservation will preserve factors of importance in the products made by the animal, as well as the health of the animal; (2) the possibility of producing cheaper milk through the use of simple nitrogen compounds in competition with protein concentrates; (3) the relation of the B complex to the growth and reproduction of swine, especially where a great deal of corn is being fed; (4) cataloguing the nutritional deficiency diseases of poultry and seeing to it that those materials that supplement our grains provide adequately the factors needed; (5) acquiring sufficient knowledge of the mineral requirements of livestock to give sound advice as to whether in all the State, or only part of it, or none of it, simple or complex mineral mixtures will be of any benefit.

After writing the "farmers' bible," Feeds and Feeding, a Handbook for the Student and Stockman (*819*),[2] F. B. Morrison, head, Department of Animal Husbandry, New York Agricultural Experiment Station, Cornell University, ought to be able to tell us exactly where the important loopholes are in our present knowledge of livestock nutrition. Here is the list of questions from him that were not answered in Feeds and Feeding, although some of them look much like the questions at the end of some of the chapters in that most helpful book:

> In reply to your letter I would state that in my opinion we need information on the following important problems, among many others in livestock feeding and nutrition:
>
> Is there any deficiency of vitamin E in normal rations for dairy cattle, beef cattle, horses, sheep, and swine?
>
> Will the addition of wheat germ oil or any other vitamin E supplement produce any benefit when added to normal rations for these classes of livestock?
>
> What are the specific fat requirements of beef cattle, sheep, swine, and poultry?
>
> Is there any lack of the so-called essential fatty acids in the usual rations for various classes of farm animals?
>
> Of what importance is the quality of protein in rations for dairy cows, beef cattle, and sheep, which are fed good-quality forage or roughage of the common types?
>
> What should be the place of legume and grass silage in American agriculture?
>
> Should legume and grass silage replace corn silage in good corn sections? To what extent should it replace hay for dairy cows in winter?
>
> What is the relative cost of total digestible nutrients and the relative cost of net energy in corn silage, legume and grass silage, and legume or mixed legume and grass hay in various sections of the United States?
>
> What is the relative value per ton of legume and grass silage in comparison with well-eared corn silage for dairy cows, for beef breeding cattle, for fattening cattle, for breeding ewes, and for fattening lambs? Is the feeding of sugar or molasses of any benefit in reducing the trouble from acetonemia[3] in dairy cattle?

Dr. L. A. Maynard is not only the author of Animal Nutrition (*769*), a book that is now filling a long-felt want for students of this subject, but he has also contributed much to several fields in the study of nutrition and lactation. His reply presents suggestions that should be given serious thought in planning experimental work. It is obviously a reflection of his 25 years of experience at the New York State College of Agriculture, Cornell University.

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[2] Italic numbers in parentheses refer to Literature Cited, p. 1075.

[3] Acetonemia is the presence of acetone bodies in the blood as the result of faulty metabolism.

In a general way I think that in the field of animal nutrition there is a need for greater emphasis on the physiological approach as distinguished from the feeding trial approach. We need to know more about what goes on inside the animal as distinguished from what goes in and what comes out. Specific problems which must have a physiological approach concern the relation of nutrition to acetonemia, milk fever, and shy breeding—border-land problems between nutrition and disease.

A problem which has important economic as well as physiological aspects is the relation of nutrition to productive life. It is apparent that we have learned to grow animals well in terms of weight and size, but we have not learned how to build the kind of body which will stand up under heavy production. This is a general statement, but it is certainly true that we have not paid enough attention to productive life as distinguished from short-time production. I am aware that breeding and disease problems are involved as well as nutrition.

With the discovery of new nutritional factors and with certain economic trends, there are increased reasons for more critical studies of home-grown feeds and of the relationship between the soil, the growth of the plant, and the nutritive value of the plant products. I am particularly impressed with the importance of this problem, which will serve to emphasize yields in terms of nutritive value instead of in terms of pounds and will recognize the importance of other nutritional factors besides digestible nutrients, protein, and even calcium and phosphorus.

NEED FOR EDUCATION

The reply of L. S. Palmer, professor of agricultural biochemistry, University of Minnesota, stresses the necessity of education in making present knowledge of nutrition effective. Dr. Palmer, a leader in research, received the Borden award in 1939 for his accomplishments. He does not decry research, but his letter deals with the aspect of our thesis which he considers most immediately urgent, namely, education.

It seems to me that the primary thesis stated in your letter involves a question of education rather than of important unsolved nutrition problems, although other discussion in your letter emphasizes the latter. I feel sure all agree it is improbable that more success may be expected in making nutrition experts out of farmers than out of any other class of laymen. For the most part, the average farmer probably needs a rise in the level of his general knowledge regarding the feeds which he uses, based upon long established principles rather than information upon recently established points. For example, farmers are still being found in northwestern Minnesota who have never even heard of bonemeal, although for the past 15 years we have been preaching its use by dairy farmers in the phosphorus-deficient areas of this State.

I believe that another example of the need for putting across to the farmer already established knowledge would be the importance of certain feeding practices and the employment of certain feeds in maintaining the nutritive value of milk at its highest level. The main facts in this field of knowledge now seem to be pretty well established and I regard it of greater immediate importance to make this knowledge a part of the average dairy farmer's knowledge than to complete the picture from a scientific standpoint. The latter, of course, should be done in connection with our fundamental research projects at the experiment stations.

I believe the problems regarding livestock nutrition which confront the average farmer are usually immediate practical problems involving choice of available feedstuffs, and these problems, I believe, are often complicated by a psychological problem arising from the temptation to accept the never-ending extravagant claims of salesmen and sales advertising for this or that feed adjunct or particular feedstuff. These are not the problems which characterize the animal nutrition projects of most of our State and Federal experiment stations and should not be the main basis of our station work in this field.

At the same time, it does seem that sales pressure for particular proprietary products is, in some instances, placing the stations on the defensive because of lack of conclusive information, which is difficult and expensive to secure. Often the propaganda is based on superficial trials carried on by the company manufacturing the product or under its auspices, or on selected data favoring the benefits of the product in question. Conspicuous examples at present are propaganda for iodine and vitamin E-containing products and, to some extent, complex mineral mixtures. The problem of the type of educational program which will protect the farmer against this propaganda until the questions involved can be settled is not easy to solve. Perhaps these are examples of types of problems which should be solved for the benefit of the farmer, but I, for one, would not advocate the direction of a major part of experiment station investigational efforts towards such problems.

No doubt, there are still examples of conspicuous gaps in nutritional knowledge for certain of our farm animals for which feeding practices still are more or less empirical. I believe this may be true regarding mineral and vitamin requirements of horses and, to some extent, sheep. However, I regard it as problematical to what extent such knowledge would help the farmer plan his feeding program more effectively. His conspicuous problems would still be the practical ones mentioned above.

H. H. Mitchell, professor of animal nutrition, University of Illinois, states:

Replying to your letter * * * the first thought that occurred to me was that the farmers, by and large, are not putting to practical use so much of the nutrition information already available. There is a big job here for the extension specialist, it seems to me.

Director E. B. Forbes of the Institute of Animal Nutrition, Pennsylvania State College, places first among three objectives in experiment station work in the interest of the producer of animals the aim "to make effective what we already know." The replies of R. A. Gortner, chief of the division of agricultural biochemistry, Minnesota Agricultural Experiment Station; M. J. Funchess, director of the Alabama Agricultural Experiment Station; E. G. Ritzman, research professor of animal husbandry, New Hampshire Agricultural Experiment Station; H. B. Ellenberger, head, department of animal and dairy husbandry, Vermont Agricultural Experiment Station; Howard Hackedorn, head of the department of animal husbandry of the State experiment station at Pullman, Wash.; I. B. Johnson, head, department of animal husbandry, South Dakota Agricultural Experiment Station; and F. W. Christensen, chairman of the department of animal and human nutrition, North Dakota Agricultural Experiment Station, all contain statements which relate more or less to the farmers' inadequate knowledge of the existing facts in nutrition.

The following quotation from Professor Christensen probably presents very well the consensus of opinion relative to the farmers' situation as regards not only existing knowledge but the field of nutrition as a whole:

A lack of understanding of the basic laws of nutrition, the nutritive value of feeds, and the normal nutritive requirements of farm animals may be a serious handicap to the farmer in planning his cropping systems and livestock programs. Because he does not understand the physiological processes of the body and how they are maintained, he is unable to fully understand and judge accurately the nutritive needs of his livestock or how to combine feeds to meet those requirements.

Lack of space prevents quoting this letter in full. It describes with very striking realism the precise conditions that must be overcome before knowledge now at hand may become effective in farm practice. This translation of knowledge into practice is a problem in education for which the research worker in nutrition is ill adapted. It requires a sympathetic and comprehensive understanding of the farmer's situation and state of mind—his conservatism, his economic condition, his natural interests and motives, and the conditions that together actuate his confidence and will to cooperate and set his mind to working.

NEED FOR RESEARCH

There is much, it is true, of the present knowledge of nutrition that should be—but is not—effective in practice; but by far the greater part of the replies stress the inadequacy of this knowledge. F. L. Bentley, head of the department of animal husbandry, Pennsylvania State College, expresses the sense of most of the replies when he says: "It seems to me that the information now available, that is of value to the farmer, is very meager compared to the future possibilities in this field."

According to L. W. Taylor, head of poultry husbandry, California Agricultural Experiment Station, the problems suggested in the replies may be classed as follows: (1) "The determination of the fundamental nutritional requirements of our animals." (2) "A fundamental study of the properties of feedstuffs and their proper combination in rations."

Dr. Mitchell of Illinois considers in his reply the present status of knowledge relative to these two aspects of nutrition problems. In view of Dr. Mitchell's work on the biological value of proteins, the amino acids in nutrition, and the utilization of energy by farm animals, and his analytical surveys published by the National Research Council on protein requirements of cattle (*795*) and the mineral nutrition of farm animals (*803*), I am glad to present a brief statement of his present views on the necessity of work in some of these fields.

> Information on the nutritional requirements of animals should be of value in farm practice, particularly with reference to protein requirements, since protein concentrates are the most expensive class of feeds. Our information on protein requirements is extremely fragmentary, especially concerning the variation with age in growing animals and with stage of gestation in pregnant females.
>
> A knowledge of nutritional requirements and the nutritive value of feeds is essential to a farmer in his evaluation of the many commercial feeds and mixtures that are on the market. I dare say that much of this business is at present an unwarrantable tax on agriculture. In particular a more complete knowledge of mineral and vitamin nutrition would save agriculture many millions of dollars at present being spent on worthless or needlessly expensive mixtures. Such knowledge would also quite probably solve obscure nutritional troubles in various parts of the country and aid in reducing mortality in young animals, particularly swine and poultry.
>
> We do not know as much as we should concerning the utilization of the nutrients in animal feeds. It is appalling to realize, for example, that somewhat over half the values for digestible nutrients given in Morrison's tables are based upon assumed digestion coefficients. Our information is even more rudimentary with reference to the wastage of minerals, vitamins, and proteins in metabolism.
>
> Average tables of feed composition are not as useful as they might be, because of the great variation due especially to variations in soil, fertilizers, and climate. There is considerable information on the effect of soil and climate on crop composition, but so far as I know it has never been organized and studied and the warranted conclusions deduced. This should be done and supplementary information on crop composition, particularly pastures, should be obtained for different

geographic localities. Then much more useful tables of feed composition could be made than are now available, and statistical methods of analysis might be found of advantage.

PROBLEMS RELATED TO LIVESTOCK REQUIREMENTS

Dr. Taylor of California suggests that the "fundamental nutritional requirements of our animals" be determined. Likewise T. P. Cooper, director of the Kentucky Agricultural Experiment Station, advocates "fundamental research in the utilization of energy by different species of farm animals." Many workers in their replies differentiated between minimum requirements—requirements to meet certain physiological criteria—and optimum requirements—that is, requirements that are optimum for some practical or economic purpose. Many replies refer to the "optimum needs of dairy cattle," "the optimum levels of protein, vitamin, and mineral intake for growth, reproduction, and special purposes," the "actual requirements of dairy cows," "the optimum level of nutrition [with poultry] that is appreciably higher than the marginal level," etc.

But it might be asked, what is meant by "fundamental" and by "optimum" levels of feeding? Director Funchess of the Alabama station says:

> The adoption of an improved practice of feeding the animals on a given farm may seem desirable from a physiological or nutritional standpoint; the farmer must be convinced that it is also desirable from an economic viewpoint. In other words, he is not interested in having better fed animals unless they make him more money.

But does this economic factor always mean feeding "appreciably higher" than the minimum? What is the criterion of "optimum"? What is meant by "fundamental" in reference to requirements? Are these not relative matters?

R. T. Clark, head of the department of animal husbandry, Montana Agricultural Experiment Station, for instance, wants to know "just what are the minimum protein requirements of sheep and cattle on our western ranges."

W. W. Burr, director of the Nebraska station, likewise says:

> The greatest nutritional problem facing Nebraska farmers in their livestock feeding operations is the lack of protein. This problem has been sharply accentuated in the last 10 years by the killing out of many acres of Nebraska alfalfa due to drought and disease. There have been many difficulties attendant on the establishment of sweetclover seedlings. I am inclined to believe, therefore, that the lack of protein is more frequently the limiting factor in the efficiency of Nebraska rations than any other one factor.

While these conditions prevail in Montana, Nebraska, and similar regions, in the South is a situation that is quite different. There little or no difference exists in some places between the cost of grain mixtures containing 16 and 24 percent of protein. Also, of course, "optimum levels of feeding" and "improved practices" that will "make more money," etc., depend upon such regionally varying economic relations as that between cost of feed and price of product. It is conditions like these that Dr. Jardine probably had in mind when he said: "Certain broad principles * * * must be tested for national, regional, and local adaptation by workers located in varying sections of the country."

An experiment with dairy cows on the relation between the level of input of feed and the output of milk, now being carried out cooperatively by the Bureaus of Agricultural Economics and Dairy Industry, together with 10 State experiment stations, is an example of the type of experiment that may give results applicable under such varied conditions. It is necessary, of course, to know the basic minimum physiological requirements of these animals and to understand the physiological conditions affecting the efficiency of the utilization of feed in order to interpret and correlate the results. It is also of advantage in planning and controlling such experiments to understand the physiological mechanism by which diet affects the secretion of milk; but to make these results broadly applicable in practice under widely differing economic conditions it is also necessary to know the average over-all relations between successive increases in feed and output. In this experiment the energy input in an otherwise complete ration is being varied, and the work is planned to throw light on the relation between yield and this variable over a wide range of feeding. It is obvious that the comparability and general applicability of such results also depends on the reliability of available digestion coefficients and knowledge of factors affecting these coefficients and feed values in general.

In considering the determination of animal requirements, it may be well to repeat Dr. Maynard's statement—"We have not paid enough attention to productive life as distinguished from short-time production"—a consideration of which would often alter the criteria used to compare various feeding regimes.

The following quotation from Dr. E. B. Meigs, Bureau of Dairy Industry, also throws light on the experimental procedure and criteria that may be considered in the study of the nutritional requirements today as compared with experimental procedures formerly used:

> I should think it would be a profitable field of research to investigate the food factors that are necessary for optimum reproduction through an unlimited number of generations in different species. It would be a large and difficult problem, but, of course, many of the easier problems in nutrition have been solved. One of the first steps would be to establish a standard of optimum reproduction on rations composed of natural foodstuffs. Probably it would be found that there is a time factor here and that even on the best rations animals would not reproduce as well in the long run if they were pushed to the greatest activity that is physiologically possible. After standards of optimum reproduction had been established on good natural rations the investigation could proceed to an analysis of the food factors contained in such rations, either by attempting to obtain similar results with more or less synthetic rations or by subjecting some of the constituents of the natural rations to heat, drying, etc.

Animals for Which Knowledge of Requirements Is Particularly Meager

The status of our knowledge of the nutritional requirements of farm animals varies decidedly with different animals. Professor Bentley, of Pennsylvania State College, says:

> The horse is probably the most neglected animal from the standpoint of experimental evidence on nutrition. * * * Mineral nutrition especially is important in horse production. We have no other class of animal in which size and quality of bone is so important, yet we have very little information. I believe that one of the most important problems from the farmers' standpoint is in this field. Horsemen are continually making inquiry as to how they can produce horses

with the quality of bone that is found in horses produced in our better bluegrass States.

Dr. Paul E. Howe, Chief of the Animal Nutrition Division, Bureau of Animal Industry, says: "Information regarding the nutritional requirements of the sheep, horse, and dog are particularly lacking."

Dr. Palmer, of Minnesota, has already been quoted as stressing the need of knowledge of the mineral and vitamin requirements of horses and, to some extent, of sheep. Director Burr, of the Nebraska station, suggests work on the "nutritional needs of service bulls and the part that nutrition plays in reproduction," and says that "comparatively little is available with regard to the effect of various dietary factors and planes of nutrition upon reproduction." E. C. Johnson, director of the Washington State station at Pullman, Wash., would determine the "actual requirements of our dairy cows" under practical conditions; and A. W. Drinkard, Jr., director of the Virginia station, says: "Information on effects of mineral and vitamin deficiencies of feeds on animals, particularly dairy cows" is much needed as well as "methods for correction of injurious effects on the animals caused by lack of minerals and vitamins." F. W. Atkeson, head of the department of dairy husbandry, Kansas Agricultural Experiment Station, believes that we need "more information on the optimum needs of dairy cattle with respect to all essential elements * * *. In the past, work has been on minimum needs. Best results require information on optimum needs of vitamins, minerals, etc." As stated above, Dr. Clark of Montana would lay stress on the minimum protein requirements of sheep and cattle on western ranges; and J. B. Fitch, chief of the division of dairy husbandry, Minnesota Agricultural Experiment Station, wants "more information on the nutritional requirements for reproduction of dairy animals."

The pig also comes in for consideration among those animals on which work should be done. Professor Bentley, of Pennsylvania, says:

> While it may seem, with all the research that has been done on the swine, that most of the important problems should be solved, they are not. A very limited amount has been done with breeding stock and the growing of young pigs. Most of our swine work has dealt with fattening swine. Unquestionably, many facts that would greatly increase our efficiency in swine production remain to be solved.

F. G. King, head of the department of animal husbandry of the Indiana station, lists among the four problems the solution of which he considers of most economic importance the determination of the "qualitative and quantitative mineral requirements of animals, especially of hogs."

Poultry received special mention. Dr. Taylor, of California, says: "Certainly it is true in the case of poultry, that we do not yet know all of the nutritional requirements of the bird"; and J. W. Kalkus, superintendent of the Western Washington Experiment Station at Puyallup, Wash., would determine "the quantitative requirements of vitamins recently found to be necessary for poultry," "the importance of rare minerals in poultry feeding" and "the fat requirements of poultry"; while Director Burr of the Nebraska station suggests that we determine "the optimum levels of nutrition" with poultry. Dr. H. W. Titus, in charge of poultry nutrition investigations, Bureau of

Animal Industry, also thinks that "optimum" requirements should be determined. R. A. Dutcher, head of the department of agricultural and biological chemistry, Pennsylvania State College, has the following to say on the protein requirements of poultry:

> The protein requirement of poultry is apparently met when the ration contains 15 percent for laying hens and 20 percent for growing chicks, provided the protein is of high biological value. This . . . has been accomplished in agricultural feeding practice by using protein concentrates obtained largely from animal sources. These are relatively expensive. Research is needed to determine how far it is possible to go in substituting different vegetable protein materials for the more expensive animal proteins.

Requirements for Particular Functions

Many of the replies stress the need for more information on the nutritional requirements for some specific function or purpose. Maynard, Meigs, Hart, and Morrison have already been quoted on this point. It is likely that some of Morrison's questions concerning vitamin E may be answered, for Gortner of Minnesota says:

> Just at present we are starting on a comprehensive project here at the University of Minnesota to determine to what extent the presence or absence of vitamin E in the diet is tied up with problems of fertility. We are going to work on dairy cattle in that problem, but there may be a different answer when we pass over to some of the other farm animals.

Some additional studies on the nutritional requirements for specific functions, suggested by various stations in addition to those already given, are listed briefly below:

Earl Weaver, head of the department of dairy husbandry, Michigan: Methods of maintaining the nutritive value of winter milk comparable to that of summer milk.

R. H. Walker, director, Utah station: Phosphorus supplement for range cattle—(a) effect on calf crop, (b) effect on development of growing range animals. * * * Nutrition and fertility of range animals * * * enabling the livestock men to increase unit production by increasing the fertility of the breeding stock by proper feeding practices. Use of beet molasses in fattening of cattle, sheep, and hogs.

G. H. Hart, head of the division of animal industry, Davis, Calif.: Basically we need to know the requirements for growth of the various species of farm animals.

F. L. Bentley, Pennsylvania: Determine the over-all effect of proper or improper nutrition upon offspring. * * * Work with all classes of breeding stock and protein, minerals, and vitamins.

E. J. Iddings, director, Idaho: Nutritional factors affecting the percent calf and lamb crop under range conditions. * * * Nutritional causes of sterility in farm stock, especially bulls.

J. O. Tretsven, dairy specialist, department of dairy industry, Montana: Nutrition in relation to sterility in dairy cattle—detailed study of vitamin E requirements for farm animals.

J. H. Zeller, swine investigations, Bureau of Animal Industry: Nutritive requirements for reproduction as they affect fertility and the size and vigor of the litter. Nutritional factors that affect milk secretion—quality and quantity of milk and its relation to growth and development of the young suckling pig.

J. B. Fitch, Minnesota: Significance of hormones in nutrition, reproduction, and milk secretion. Nutritional requirements for reproduction of dairy animals.

R. E. Buchanan, director, Iowa: Nutrition in relation to reproduction. Factors involved in economical production of milk, eggs, and meat of maximum nutritional value.

R. T. Clark, Montana: Fattening rations for lambs; use of beet byproducts.

E. B. Meigs, Division of Nutrition and Physiology, Bureau of Dairy Industry: Most dairymen would have no doubt that cows could not be kept milking satisfactorily very long if they were given no dry periods at all. It is not a purely nutritional problem, but is probably intimately connected with nutrition in the sense that dry periods could be made shorter on better rations than on less adequate ones. This has been very little investigated, as far as I know, and it seems likely that results of considerable practical importance might be obtained fairly quickly.

H. C. Jackson, chairman of the department of dairy industry, Wisconsin: The effect that various feeds may have on the chemical and physical nature of the milk produced.

G. Bohstedt, professor of animal husbandry, department of animal husbandry, Wisconsin: Relation of feed to the butterfat percentage of milk or to the fat production of dairy cows.

F. J. Sievers, director, Massachusetts: Relation of feeds and feeding practices to the off flavors in milk—"cardboard" flavor.

RELATION OF NUTRITION AND FEEDING MANAGEMENT TO HEALTH AND DISEASE

The relation of nutrition to disease received frequent consideration in the replies. Some suggested work on "the recognition of nutritive disturbances," as Samuel Lepkovsky of the department of poultry husbandry, California, put it. Dr. Titus of the Bureau of Animal Industry says: "More should be known about the symptoms of partial nutritive deficiencies, both simple and multiple"; and Dr. W. M. Neal, of the department of animal husbandry, Florida station, suggests a "study of histo-pathology [4] of nutritional disorders." Lepkovsky would study "depraved appetites" in this connection.

Maynard, Morrison, and Hart have already been quoted on disease problems. Possibly it would be well to list briefly some additional problems suggested on the relation of nutrition to disease.

Samuel Lepkovsky, California: Relation of rate of growth to health and vigor. Possible relation of nutrition to mortality.

Hadleigh Marsh, head of the department of veterinary science, Montana: Nutritional requirements from the standpoint of health rather than production of meat or milk * * * nutritional sufficiency, from health standpoint, of range feeds under various conditions.

R. E. Buchanan, director, Iowa: Effect of nutrition on susceptibility of farm animals to disease.

J. B. Fitch, dairy husbandry, Minnesota: Relation of nutrition to mastitis.

A. A. Borland, head, department of dairy husbandry, Pennsylvania: Does the plane of nutrition in the feeding of dairy cows affect their resistance to mastitis? * * * Relation of pneumonia in newly born calves to the nutrition of the dam during pregnancy.

L. F. Payne, head, department of poultry husbandry, Kansas: A more intensive study of the relation of nutrition to the heavy mortality in poultry flocks the first laying year.

R. S. Besse, vice director, Oregon: In all probability there is some relationship between high mortality among ewes in western Oregon at certain seasons of the year and some nutritional disturbance.

A. G. Hogan, professor of animal nutrition, department of animal husbandry, Missouri: A considerable number of young of swine, cattle, and sheep have been reported dead or weak at birth. Is the difficulty due to failure to provide enough green forage and reliance on straw with limited grain feeding? "Several cases have been reported of animals with very weak or porous bones." Is this condition due to the use of roughages such as straw and of grains which are very low in calcium?

F. W. Atkeson, Kansas: Methods of feeding or management to control bloat.

E. J. Iddings, director, Idaho: Nutritional factors responsible for the occurrence of bloat. Cause of abnormal sugar metabolism in ewes and cows. Cause and prevention of urinary calculi in sheep. Relationship of nutritional factors to the incidence of swine arthritis.

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[4] Histopathology is the histology (microscopic anatomy) of tissues under various pathological conditions.

C. W. McCampbell, head, department of animal husbandry, Kansas: Is "lambing disease" in ewes nutritional in origin?

E. B. Stanley, head, department of animal husbandry, Arizona: Losses among stock running on pasture, that cannot be attributed to any known form of disease. He believes that certain substances in the pasture feed itself may be responsible.

F. L. Bentley, Pennsylvania: Relation of nutrition to a condition "similar to rickets" in swine.

R. A. Gortner, Minnesota: Minimum tolerance of livestock for fluorine.

NUTRIENTS FOR WHICH A KNOWLEDGE OF REQUIREMENTS IS PARTICULARLY LACKING

Protein

Some replies state that the requirements for all nutrients should be determined (see earlier quotations from Hart and Mitchell). J. H. Skinner, director of the Indiana Agricultural Experiment Station, says, "There are still many problems in animal nutrition having to do with the place and importance of minerals, proteins, and fats."

It will be noted, however, that Burr, Clark, Mitchell, Morrison, and Dutcher all stress the economic importance of the protein problem. H. R. Kraybill, head of the department of agricultural chemistry, Indiana Agricultural Experiment Station, says: "Further information is needed also on the protein requirements of livestock with particular reference to the economic use of the proteins." The following occurs in the reply of Gortner of Minnesota:

> I think that we have to emphasize not only an adequate amount of proteins but also the fact that the proteins themselves must be adequate, and some of the work that Dr. Palmer has been doing would appear to indicate that the protein of prairie hay is not only inadequate in amount but also inadequate insofar as quality is concerned.

Although the protein problem has certain regional aspects, the demand for work on protein requirements of livestock and methods of supplying these requirements is very widespread. R. E. Hodgson in the dairy department and G. E. Bearse in the poultry department of the station at Puyallup, Wash., suggests a study of the "quality of protein in different kinds of roughage and the influence of stage of maturity and method of preservation on the quality of protein"; while to quote W. C. Skelly, animal husbandman, New Jersey State Agricultural Experiment Station, "The protein requirements * * * should be stressed as much as possible."

The problem of protein requirements is also stressed in its relation to various functions.

Fats

The work that has been done on the essential fatty acids—linolenic, linoleic, and arachidonic (see the article Human Food Requirements—Carbohydrates, Fats, Energy, p. 152)—recognized as essential with the rat, and on the effect on milk secretion of minimum amounts of fat in the diet, brought repercussions in the replies. The following suggestions were made in addition to the questions of Morrison, already quoted:

H. R. Kraybill, Indiana: Information is needed on the amount of fat required in rations of various farm animals.

F. G. King, Indiana: The dietary fat requirements of animals [should be determined.]

H. B. Ellenberger, Vermont: The fact that many of our feeds are lower in fat content than they used to be, and the importance of fat in the ration, should be more definitely explained.

G. C. White, Department of Dairy Industry, Connecticut: Another phase of this subject of nutrition on which we are in need of more information as soon as possible is the role of fatty acids in nutrition, especially as it may be affected by the level of vitamin intake. We are also interested in the total amount of fat in the rations of herbivorous animals at different levels or rates of production.

It might also be asked what fat acids are necessary in the diet for milk secretion—all of them, certain specific acids, or certain groups of acids?

Minerals

Elsewhere in this Yearbook there is a report of a survey to determine from the State stations what they know about the mineral deficiencies in their States. It will be noted that an appalling lack of definite information prevails in most sections. In the replies to my letter, Professor Gortner of Minnesota says:

> Then we have the big problem of mineral metabolism. As you are fully aware, large areas here in the Middle West are deficient in phosphorus. Just how large this area is, we do not know. We have the Minnesota picture fairly well outlined. This comes up flat against the borders of both North and South Dakota. How far into those regions, we do not know * * *.

Professor Hart of Wisconsin lists mineral requirements as a "local" problem. According to the information from the stations, a solution to this "local" problem is urgently needed in many States, in order that livestock, especially cattle, may be either better fed or fed without expenditure of money for unnecessary or unsuitable mineral mixtures.

We need to know (1) the mineral requirements of livestock, quantitative as well as qualitative, for growth, maintenance, production, and reproduction, and (2) the adequacy of diets in supplying these requirements under different feeding regimes—range, pasture, hay-silage-grain feeding, etc., with feeds produced under varying conditions and in various regions. This may require regional surveys where evidence warrants the expenditure. These problems are stressed widely in the replies to my letter. Drinkard of Virginia, Bohstedt of Wisconsin, and Zeller of the Bureau of Animal Industry would include the "rarer minerals" or "trace" elements in this investigation. Bohstedt suggests investigation of "the importance of trace mineral elements such as cobalt and manganese in animal nutrition." "Are there regions in the United States," he asks, "where there is a deficiency of some of them, as a cobalt deficiency has been found in regions of Australia and New Zealand?" Undoubtedly the requirements for all essential minerals should be determined; forage and feed analyses will then be very much more significant in indicating areas where deficiencies may be suspected; and diseases and difficulties with livestock that are of endemic (local) nature should be investigated to determine whether or not they are of nutritional origin.

Vitamins

The pioneer days in vitamin work are fast passing. It is true that additional vitamins are certain to be discovered, but many of them have now been isolated in pure crystalline form, and their chemical structure has been determined and their chemical synthesis accomplished. Chemical and physicochemical methods of assay are in use with some vitamins and are being developed with others. The studies now in progress on the metabolism and physiological functions of the known vitamins forecast the use in the near future of more refined physiological techniques instead of gross pathological symptoms in the detection of vitamin deficiencies. Despite the very considerable removal of barriers to profitable research in the study of the vitamin requirements of livestock and the vitamin values of feeds, there is, as Kraybill of Indiana says, further need for improved methods for measuring the vitamin content of various feeding stuffs; and Mitchell of Illinois would undoubtedly characterize present knowledge of the "wastage" of the vitamins in metabolism as very rudimentary. In responses from the various experiment stations there are numerous demands for work on the vitamin requirements of livestock and on methods of supplying them, both for proper feeding and, as some have put it, to guard the farmer against misinformation.

Work on vitamin E at Minnesota, mentioned by Gortner, is being done first with dairy cattle. Hogan, of Missouri, refers to vitamin A deficiencies with sheep and cattle during the winter, owing possibly to previous exceedingly dry weather which made green feed very scarce. Clarence Dorman, acting director, Mississippi, says: "Our experiments at present point toward vitamin A deficiency in our roughages as a limiting factor in livestock production." Hart's mention of the vitamin B complex in relation to the growth and reproduction of swine has already been quoted. Professor Iddings, Idaho, proposes a study of the "quantitative vitamin requirements of livestock" and the "vitamin content of different farm feeds and factors affecting their preservation." Director Burr of Nebraska makes a similar suggestion; and S. S. Wheeler, professor, department of animal production, Wyoming, believes further work is necessary on vitamin A requirements.

Miscellaneous Factors

Meigs, Bureau of Dairy Industry, says that a—

> line which ought to be interesting to cattlemen is that of the possible nutritive essentials which are manufactured by bacterial action in the bovine paunch. It has always seemed to me that the leads given by Bechdel and Eckles [and associates (*75*, *79*)] in this direction deserve more following up than they have received thus far.

Perhaps the problem of "the possibility of producing cheaper milk through the use of simple nitrogen compounds in competition with protein concentrates," suggested in the letter of Hart, of Wisconsin, is akin to this problem suggested by Meigs. Drinkard, of Virginia, proposes "research giving more information regarding the significance of plant enzymes in animal nutrition, including the action of these enzymes in the hydrolysis of plant tissue in the rumen."

Several stations in their replies propose work on the metabolism of the hormones and the nutritional conditions that may affect their formation and functioning. In addition to this, estrogenic materials—materials that produce estrus in females—have been discovered in plants, and material has been found in young growing plants that has a gonad-stimulating effect similar to that of the gonad-stimulating hormone secreted by the anterior lobe of the pituitary gland. There is now much circumstantial evidence in the literature of still undiscovered nutritive factors in plants.

E. B. Forbes, head, department of animal nutrition, Pennsylvania, would "continue the quest for knowledge of fundamental details of nutritional physiology—to afford guidance in feeding and in selective breeding."

FEEDS AND FEEDING REGIMES

I have considered above some of the suggestions that bear principally on requirements of specific animals, for specific functions, and in respect to specific nutrients, as well as on problems of the relation of nutrition to disease. The need for further work on feed values and on the feeding regimes that may be used to meet these requirements was very extensively stressed. There were at least 40 references to problems in connection with pasture and range feeding, and the demand for further work on the production, preservation, and utilization of hays and silages indicates intense and active interest in these fields at the present time. The following brief excerpts from these letters may indicate something of the nature of the interest:

Problems Relating to Forages in General

Johnson, director, Pullman, Wash.: The greatest problem which faces the dairy industry from the standpoint of the nutrition of dairy cattle is that of roughage feeding. * * * Mineral contents of our forage crops, particularly * * * calcium and phosphorus.

Buchanan, director, Iowa: [Would study] the role of roughage in the ration of ruminants.

Johnson, South Dakota: [Work on the] digestibility and comparative feeding value of roughages from different grasses is badly needed.

Kalkus, superintendent, Western Washington Experiment Station: Quality of protein in different kinds of roughages and the influence of stage of maturity and method of preservation on the quality of the protein. * * * Costs of producing nutrients in various roughage and grain crops and the relative costs of different methods of harvesting and preserving nutrients for winter feeding.

Weaver, Michigan: Specifically with given roughages, how far should our dairymen go in providing concentrates?

Ellenberger, Vermont: [Would study] the problems connected with feeding more and better roughages and the profit in improving pasture and hay lands and feeding little or no grain. Of course high producing cows must have liberal grain rations. * * * The relative returns from liberal versus scanty grain feeding should be better understood. * * * More should be known about the amounts, qualities, and economies of nutrients derived from pasture. Also the differences in quality which may result from fertilization and stage of growth when pastured. * * * We need still more knowledge relative to practical methods of preserving grass and legumes for silages and the relative losses from different haying and ensiling methods.

M. Jacob, head, department of animal husbandry, Tennessee: [Effect of] soil improvement on the nutritive value of grazing, hay, and silage crops.

Drinkard, director, Virginia: The development of grazing crops particularly on land that should not be plowed. (a) Strains of bluegrass, clover, and other grasses that yield more forage during midseason and dry periods. (b) Introduction of forage crops suited to climatic conditions in the South. * * * Complete mineral analyses of different plants used in feeding cattle * * * Conditions under which low and high percentages of minerals are produced in forage plants * * * Vitamin contents of roughages and grains * * * Improvement of the mineral and vitamin content of plants used in feeding cattle by plant breeding methods * * * Methods by which plant deficiencies, particularly mineral and vitamin deficiencies, may be corrected * * * Supplementary value of plant proteins.

K. S. Morrow, dairy husbandman, department of dairy industry, New Hampshire: Interested in grass silage. More consideration should be given to the quality of * * * dry roughages, especially native hay such as timothy, which can be grown in New England * * * I presume no one knows definitely what is the most favorable balance of nutrient source between grain and hay or roughage from the standpoint of production * * * or economy of feeding practices.

Johnson, South Dakota: Feeding value of roughage stored under various conditions for more than 1 year—and of other feeds also. Information is needed concerning the use of sorghum for forage and for grain for livestock.

Payne, Kansas: Methods and means of producing and preserving young forage crops especially applicable to feeding poultry * * * Nutritional factors present in young forage crops which so far do not seem to be preserved in dry or dehydrated forms * * * Careful study of young forage plants to ascertain, if possible, what it is that gives the high nutritive value [to them].

T. E. Woodward, Bureau of Dairy Industry: Raise and feed more high quality forage—pasturage, hay, and silage. This can be recommended without further research. Further work is needed on the harvesting and storing of forages with a view to conserving more fully the nutritive value and palatability of the green plants without at the same time incurring any considerable extra expense * * * It would be of use, too, to know the cropping system best adapted to any particular soil and climate, both when the main source of income is the sale of milk and when it is the sale of cream and hogs * * * How best to supplement forages with more concentrated feeds. We are particularly in need of investigations that will show the quantities of concentrated feed which should be given to cows with forages of different qualities when the prices of the feed and product vary considerably * * * Still another problem upon which we need more information is the relative nutritive value of different feeds.

Bohstedt, Wisconsin: Effect of seasons of drought or excess rainfall upon the composition and feed value of plants.

Problems Relating to Pasture Feeding

The use of pasture received wide attention in the letters received. Prof. G. C. Humphrey, department of dairy husbandry, Wisconsin, says:

> I should say first of all we have not established the value of good pasture to the extent of showing facts on how pasture influences health, growth, maintenance, and productivity of our farm animals.

W. C. Coffey, director, Minnesota, says:

> I strongly incline to the importance of a program addressed to the nutritional and management phases of grass in animal production. There is a general awakening to the importance of this problem and I sincerely hope that the next 10 years of research will yield significant results relative to grass. Perhaps I should include the word forage.

Wheeler, Wyoming, says:

> Another problem which seems to us particularly timely is that of the nutritive value of permanent pastures. We have reference in this connection to the so-called irrigated pastures of tame grass and legume seedlings. The nutritional aspects of pasture research are, to our way of thinking, rather important. Little is known in this section of the country regarding this type of permanent pastures, and very little more is known regarding the carrying capacity and management problems.

In Arizona, Stanley also would investigate the—

> use and value of our pasture feeds in the irrigated sections. An increasing use is being made of pasture feeds, particularly alfalfa in combination with barley in the irrigated areas, and no definite information is available pertaining to the exact value of this kind of feed. While stockmen, particularly sheep and cattle men, have been using these feeds for some time, they are increasingly dependent upon them. There is no knowledge concerning the most practical method of using these feeds nor as to their value as feed.

King, Indiana, suggests a study of the "nutritive value of pastures, and the effect of fertilization and management of pastures on feeding value"; Zeller, Bureau of Animal Industry, proposes a study of the nutritive value of different pasture grasses; while Cooper, director, Kentucky, would investigate "the nutritional value of pastures for poultry."

Several workers believe, as Weaver (Michigan) puts it, that there is "urgent need of unification in our methods of evaluating pastures. Possibly some further work along this line might afford facts upon which we might unify our pasture research." Kalkus, Puyallup, Wash., expands this thought somewhat when he emphasizes the need of "methods of measuring pasture yields in terms of grazing animals." He also sees need for "knowledge of nutrient requirements of cows under grazing conditions," and on "the effect of pasture management upon yield and palatability of pasture"; also the effect of stage of maturity at cutting and the methods of processing. Johnson of Pullman, Wash., feels that work should be done on methods of determining and expressing "pasture yields," and Atkeson, dairy husbandry, Kansas, sees the need of "more information on the best methods of pasture management." Again and again the necessity of more information regarding the mineral, vitamin, and protein content of pasture herbage and the factors affecting these values is stressed. The fact also should not be overlooked that there are undoubtedly undiscovered nutritive factors in pasture, and several replies suggest further investigation of these various "grass factors."

Range Feeding

Some of the problems suggested that pertain particularly to range feeding are indicated in letters from stations where this type of feeding is important.

Clark, Montana: I am firmly convinced that there is a crying need for some fundamental research on the food value of grasses that are native to Montana ranges * * * I believe that it is highly desirable that this experiment station examine the food value of certain introduced species of grass, more particularly crested wheatgrass * * *

Wheeler, Wyoming: A more careful appraisal of the value of native grasses and other forage plants used for wintering sheep and cattle. We have a fairly comprehensive amount of information on the chemical analysis of range forage plants, but to my knowledge little, if any, information on their actual efficiency. The field of mineral nutrition in the western area has barely been scratched. There exists, in our opinion, a wide variation of conditions throughout this area together with a variety of opinions regarding the necessity of feeding supplementary amounts of minerals to sheep and beef cattle. The work that has been done so far points to no definite conclusions. It seems to me, therefore, that further work along the line of determining more accurately the mineral requirements of range sheep and cattle would not be unjustified.

G H. Hart, California: [Study the] deficiencies of feeds available in considerable quantities in local areas in order that their limitations could be recognized and the deficiency supplied at minimum cost * * * Possibilities and limitations of range forage and how best to supplement it for stock cattle as compared with fattening cattle. For example, remarkable results can be obtained in this State by feeding the cow herd one or two pounds of cottonseed meal on our ranges where annual vegetation constitutes the cover, provided this is started early enough before the animals get too thin.

Besse, Oregon: The outstanding unsolved problems in the field of animal nutrition as they appear to us in Oregon are divided into two general classes:

(1) The problems affecting the livestock in western Oregon and on the irrigated

areas of southern and eastern Oregon. These problems have to do mainly with dairy cattle and sheep and unquestionably involve phosphorus deficiencies in forage crops and in the grains and probably some vitamin deficiency in the cured forage crops and the relationship of these two probable deficiencies. There is plenty of evidence of definite phosphorus deficiency in several areas abovementioned, particularly as its effect is observed with dairy cattle. In all probability there is some relationship between high mortality among ewes in western Oregon at certain seasons of the year and some nutritional disturbances. Just what these are has not been determined.

(2) The other principal division in which livestock nutritional problems fall has to do with the nutrition of range livestock. Fragmentary analyses of natural forage, bunch grass, browse, etc., collected throughout the range country, as well as similar analyses of both wild and tame hays on which range cattle are wintered, indicate a high variability of protein and phosphorus content. The deficiency of phosphorus in many of our valleys in eastern Oregon has shown the phosphorus content of hay is below the minimum requirement for optimum nutrition. This is also true of the analysis made of many of the dried forage plants which the animals consumed in the dried or cured form on the range. From experience of workers in California, there is every reason to suspect a deficiency of vitamin A and probably D in many of these forage plants.

Stanley, Arizona: A publication reporting the results of a study of the nutritional requirements of cattle on a grass land range area in this State has just been published * * * A phase of this study is being enlarged to include forages from representative range areas throughout the State. Standard feed analyses including phosphorus and carotene determinations are being made of these forages at different seasons of the year. Blood samples are also being taken of cattle grazing on these range areas for phosphorus determinations. We are hopeful that after another year or two of study on this problem that this station will have a more definite knowledge of the actual nutritional value of our more important range feeds.

Iddings, Idaho: The nutritive value of the major species of range forage plants with special reference to the total digestible nutrients present at different stages of growth * * * Mineral deficiencies of range stock.

Walker, Utah:

1. Additional studies to determine the seasonal variation of the composition of range plants, particularly in regard to the amounts and proportion of the essential mineral constituents. Information of this type would enable the range livestock operator to more intelligently supplement the range feeds during times of stress.

2. The influence of unusual soils (alkaline, acid, calcium deficient, seleniferous, etc.) should be a very beneficial type of study. Although information derived from this type of research may not be applicable to large areas, it should prove very helpful in solving some feeding problems of a specific nature.

3. A study of the influence of prolonged droughts on the composition of range plants and their effect on range animals would prove very valuable in arid range sections.

4. A study of the relationship between nutrition and fertility of range animals might prove to be very valuable in enabling the livestock men to increase unit production by increasing the fertility of the breeding stock by proper feeding practices.

5. A study of the manganese content of feeds grown in this region and the influence this element may have on the development of bone deformities occurring in partly grown lambs and turkeys.

6. A survey to determine the localities in our State in which the soils, plants, or animals are deficient in phosphorus (in the case of soils, available phosphorus).

7. Value of a phosphorus supplement for range cattle on Utah ranges. (a) Effect on calf crop; (b) effect on development of growing range animals.

8. The optimum amount of beet molasses for feeding both cattle and sheep which are being fattened.

9. The optimum amount, also the value, of beet molasses for fattening hogs.

J. H. Knox, head, department of animal husbandry, New Mexico: We believe that more information about composition of range plants is greatly needed * * * Should not only give average compositions for the principal species, but should also show how they are affected by soil, climate, stage of maturity.

Hays and Silages

C. F. Huffman, research associate in dairy husbandry, Michigan, sets up only one problem in his reply. It is a study of "the nutritive value of roughages and methods of conserving roughages before digestibility of the dry matter is depressed." Hart, Morrison, and Mitchell have already been quoted on this and related problems.

Other suggestions for work on hays and silages may be given briefly as follows:

Humphrey, Wisconsin: I feel that we should have more facts on what constitutes good roughage for winter rations.

Bohstedt, Wisconsin: The factors that make for satisfactory hay and silage, with reference to palatability, preservation of nutrients, and absence of mold.

Ellenberger, Vermont: We need still more knowledge relative to practical methods of preserving grass and legumes for silage and the relative losses from different haying and ensiling methods.

Sievers, Massachusetts: Methods of preserving and utilizing roughage * * * Grass silage * * * Artificial use of acid preservatives in silage * * * Stage of maturity for the harvest of roughage.

C. B. Bender, professor of dairy husbandry, State College of Agricultural and Mechanic Arts, New Brunswick, N. J.: Grass silages should be investigated quite thoroughly within the next few years. This subject is coming into considerable prominence because of its distinctive value in a system of agriculture. We have been doing considerable work along these lines, but I feel that it is extremely essential that other experiment stations try out this material on various breeds of livestock. First, to find out the exact feeding values of the various crops that may be ensiled, then to find out what effect the maturity of the crop will have upon the feeding value. Also, to find out what effects the kind and amounts of preservatives will have on the feeding value of the crop, as well as their effect on the physiological reaction of the animal. I know that the quality of roughage is extremely important in determining the feeding value, and from our experiments we definitely feel that by ensiling green crops we may preserve the roughages when they have their highest nutrient value.

Atkeson, Kansas: The place of grass silage in the best dairy farm management. Better methods of hay making to recover more completely the entire nutrients produced, in the most palatable and nutritious form. More research on what constitutes quality in hay for dairy cattle: methods of measuring same; and adjustment of hay grades on this basis.

P. S. Burgess, dean and director, Rhode Island station: Professor J. E. Ladd, head of our Department of Dairy Husbandry, has suggested that studies on the change in the kind and amount of concentrated feeds now needed to meet better roughage practices (grass silage, etc.) to reduce the cost of making market milk, is the big problem now before dairymen in this State.

Borland, Pennsylvania: The physiological effects of phosphoric acid in amounts such as are ordinarily used in the preservation of grass silage (1¼ gals. or 16 lbs. per ton of green forage).

Problems Relating to Feed Values in General

Some workers (Woodward, Bureau of Dairy Industry, Weaver, Michigan, and others) feel that the method of expressing the energy values of feed in terms of total digestible nutrients is unsatisfactory. Mitchell has already been quoted as saying that "average tables of feed composition are not as useful as they might be."

The variability in the composition of feeds is generally recognized. Dutcher of Pennsylvania says:

> Home-grown grains used so extensively in poultry feeding vary in mineral, vitamin, and protein content depending upon the area in which they are grown and the types of soil peculiar to these areas * * * Considerable research work is necessary before it is feasible to recommend the amount of supplementary grains to be fed to poultry under various conditions of feeding.

Titus, poultry nutrition, Bureau of Animal Industry, comments:

> We know in a crude way, as the result of proximate analyses, the percentage of protein, fat, fiber, ash, moisture, and nitrogen-free extract in many of our feedstuffs. We also know something about the relative value of some of them as sources of good protein and the several vitamin and inorganic elements. But * * * our knowledge is very incomplete.

Taylor, poultry, California, voices a general feeling when he proposes "a fundamental study of the properties of feedstuffs and their proper combination into rations." Some workers—for example, Woodward of the Bureau of Dairy Industry—feel, as Knox (New Mexico) puts it, that "from the standpoint of the livestock feeder, we believe that more complete and more definite knowledge of the net energy value of feeds is the most important contribution that could be made"; others recognize the difficulty in determining such values for individual feeds. J. C. Knott, associate dairy husbandman, Pullman, Wash., says: "Our greatest need in the nutrition of dairy cattle is to know the nutritive value of the complete ration," and "We need further information on the proper feeds that will supplement our home-grown roughages."

Buchanan (Iowa), King (Indiana), Fitch (Minnesota), Zeller (Bureau of Animal Industry), McCampbell (Kansas), Burr (Nebraska), Drinkard (Virginia), Ellenberger (Vermont), and Lepkovsky (California) all suggest work on the protein value of feeds—the biological value of the protein, the supplemental relation between feed proteins, the amino acids in feed proteins, the conditions affecting the protein value of feeds, economical sources of proteins, etc.

Under this heading there are about 14 proposals for work on the mineral contents of feeds. Work of this sort is advocated in replies from Virginia, Pennsylvania, South Dakota, Montana, Mississippi, Tennessee, California, Utah, Oregon, Washington, Illinois, Nebraska, Wyoming, and Wisconsin. Some of these replies have already been referred to. A number of them propose to investigate the question of phosphorus deficiency. Some would investigate the possibility of both calcium and phosphorus deficiencies, while others would include a study of manganese, cobalt, and iodine in feeds.

I shall not attempt to summarize the above suggestions. As stated at the beginning, the problems suggested deal with every aspect of livestock nutrition. After reading them, I realized that they cover the entire subject matter of this Yearbook. In closing this inadequate summary, I want to thank all who replied to my letter.

COMPOSITION OF THE PRINCIPAL FEEDSTUFFS USED FOR LIVESTOCK

by N. R. Ellis, W. R. Kauffman, and C. O. Miller[1]

TABLES of composition of feedstuffs have found widespread use among those concerned in livestock feeding. Such information is especially useful in the selection of feeds and the determination of the proportions to use in diets. State and Federal regulations governing the sale of feedstuffs frequently include provisions concerning the protein, fiber, ash, fat, and moisture content. In the use of forage crops, it is now realized that stage of maturity is an important factor in composition. Estimations of the digestible nutrients contained in a given feed are based on the percentages of total protein, fat, fiber, and nitrogen-free extract (carbohydrate except fiber) and the coefficients of digestibility, which have been determined experimentally. Thus it can be seen that tables of composition are useful in a variety of ways.

The data assembled in table 1 cover the more common constituents found in feedstuffs. They include those concerned in protein, energy, calcium, and phosphorus metabolism. The table represents a revision of earlier tables in use in the Department. An effort has been made to incorporate recent analyses of materials as they are used today. Such changes in composition as have occurred may be attributed to improved methods of analysis, introduction of new varieties of plants, changes in harvesting methods, and improvements in milling and processing methods.

Wherever possible, the definitions and standards for feedstuffs that have been adopted by the Association of American Feed Control Officials have been followed in the selection and arrangement of the analysis figures. The data on composition have been taken from the publications of the State experiment stations, the State and Federal regulatory agencies, and other publications on the feeding and nutrition of animals. While the compilations are by no means complete as to numbers of analyses and materials, they are offered as typical of present-day products.

Table 2 gives the estimated digestible protein and total digestible nutrients of those feeds listed in table 1 for which digestibility coefficients have been determined for cattle, sheep, and swine. Though it has been customary to combine the data for ruminants, recent interest in species differences has prompted the separate treatment in the present table. Data for poultry will be found in table 8 of the article

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[1] N. R. Ellis is Senior Chemist, W. R. Kauffman is Assistant Chemist, and C. O. Miller is Junior Scientific Aid, Animal Nutrition Division, Bureau of Animal Industry.

Practical Feeding of Poultry (p. 842). In the preparation of table 2, advantage has been taken of various publications, especially those of the Texas Agricultural Experiment Station, in which digestibility coefficients have been assembled.

These data are presented for the purpose of showing the extent to which studies on the digestibility of individual feedstuffs have been carried and to show the likenesses as well as variations between species. It will be noted that sheep have been used much more extensively than either cattle or swine for determination of digestibility. The work with swine has been confined largely to the grains, seeds, and protein concentrates. No attempt has been made to determine the reliability of the figures through evaluation of the errors involved in the averaging of data from various sources. Hence, unless differences in digestibility between animals or feeds are reasonably pronounced, they may not mean a great deal.

Undoubtedly, the most accurate data on digestibility are obtained and the most reliable application is made on the basis of the actual combination of feeds used in the diet of a particular class of animal. Values for single feeds are not necessarily reproducible in a mixture, and values obtained on high-producing milking cows are different from those on dry cows. An extensive number of diets containing several feeds have been studied, but these diets have not been tabulated here because of the complexity of the data.

Critical studies on the relationship between the over-all nutritive value of feeds as shown in the feed lot and the data on composition and digestibility have revealed various pitfalls in interpreting nutritive values from the composition data. The question has become of such interest that the American Society of Animal Production has appointed a special committee on the evaluation of feeds. This committee has planned to consider feed from various viewpoints including (1) energy, (2) total nutritive value, (3) biological methods for studying protein and energy values, (4) chemical methods, and (5) digestibility by different species. One of the more difficult chemical problems is the expression of the carbohydrate fractions commonly given as the crude fiber and the nitrogen-free extract. This arbitrary division does not measure especially well the nutritive value of the several chemical constituents which include the sugars, starches, pectins, gums, hemicelluloses, celluloses, and lignins. The discrepancies are reflected especially in the evaluation of the energy content of the forages and other products containing the more indigestible constituents. The important role that vitamins and minerals play in the ability of the animal to utilize feed will require the reexamination of the older data on energy and protein values, which may have been obtained during the feeding of rations deficient in these other nutritive factors.

Finally, it should be pointed out that such differences as may be found between the present values for digestible constituents and other published values may be due to several factors. In the first place, the chemical composition data of table 1 show differences from other published tables due to selections made in the compilations. Considerable latitude must be permitted in the choice of digestibility coefficients suitable for general use. Coefficients for a given constituent and feed vary considerably and unless a large number of determinations are available to be averaged the use of any unusually high or low values in one case and not in another changes materially the final digestibility value. The separate treatment of sheep and cattle in the present tabulation as contrasted with the usual combination of all species or of all ruminants also has an important bearing on the calculations. On the whole, the present values appear to show good agreement with other published figures in most instances.

TABLE 1.—*The percentage composition of feedstuffs used in animal feeding*

GRAINS, SEEDS, AND MILL CONCENTRATES

Feedstuff	Moisture	Ash	Crude protein	Ether extract[1]	Crude fiber	Nitrogen-free extract[2]	Calcium[3]	Phosphorus[3]
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Barley	9.6	2.9	12.8	2.3	5.5	66.9	0.07	0.32
Barley feed	7.9	4.9	15.0	4.0	13.7	54.5	.03	.41
Bread, kiln dried	10.5	2.1	12.5	1.6	0.4	72.9	.03	.12
Brewers' dried grains:								
18-23-percent protein	7.9	4.1	20.7	7.2	17.6	42.5	.16	.47
23-28-percent protein	7.7	4.3	25.4	6.3	16.0	40.3	.16	.47
Brewers' rice	11.6	.7	7.0	.8	.6	79.3	.03	.25
Buckwheat	12.6	2.0	10.0	2.2	8.7	64.5	...	...
Buckwheat middlings	12.4	4.6	28.0	6.6	5.3	43.1	...	...
Cocoa shells	9.2	8.2	16.4	5.4	15.8	45.0	...	...
Coconut cake	10.7	4.0	19.1	11.0	14.1	41.1	...	...
Coconut meal, old process	7.3	5.5	21.3	10.0	9.4	46.5	.28	.58
Coconut meal, new process	8.9	6.6	21.4	2.4	13.3	47.4	.28	.58
Corn, shelled	12.9	1.3	9.3	4.3	1.9	70.3	.01	.26
Corn bran	10.0	2.1	10.0	6.6	8.8	62.5	.03	.14
Corn chop	11.3	1.4	9.8	4.1	2.1	71.3	.01	.26
Corn (ear) chop	10.7	2.0	8.2	3.4	9.2	66.5	...	...
Corn-feed meal	10.8	1.9	10.5	5.3	2.9	68.6	.04	.38
Corn-germ meal	7.0	3.8	20.8	9.6	7.3	51.5	.05	.59
Corn-gluten feed	9.5	6.0	27.6	3.0	7.5	46.4	.11	.78
Corn-gluten meal	8.0	2.2	43.0	2.7	3.7	40.4	.10	.47
Corn-oil meal	8.7	2.2	22.1	6.8	10.8	49.4	.06	.62
Cottonseed, whole pressed	6.5	4.3	29.6	5.8	25.1	28.7	...	...
Cottonseed cake	7.5	5.9	44.1	6.4	10.3	25.8	...	...
Cottonseed feed, 32 percent protein	8.3	4.8	32.1	6.4	15.3	33.1	.20	.73
Cottonseed hulls	8.7	2.6	3.5	1.0	46.2	38.0	...	...
Cottonseed meal:								
33-38 percent protein	7.4	5.2	36.6	5.6	15.3	29.9	.28	1.30
38-43 percent protein	7.3	6.1	41.0	6.5	11.9	27.2	.19	1.11
Over 43 percent protein	7.2	5.8	43.7	6.5	11.1	25.7	.18	1.15
Distillers' (corn) dried grain	7.0	2.4	28.3	9.4	14.6	38.3	.04	.29
Distillers' (rye) dried grain	6.1	2.4	17.9	6.3	15.9	51.4	.13	.43
Feterita	9.1	1.7	14.2	2.9	1.4	70.7	...	...
Hemp cake	10.8	18.0	30.8	10.2	22.6	7.6	...	...
Hempseed, European	8.8	18.8	21.5	30.4	15.9	4.6	...	...
Hominy feed	9.5	2.9	11.2	8.3	6.3	61.8	.03	.44
Kafir	11.9	1.7	11.1	3.0	2.3	70.0	.01	.25
Kafir-head chops	10.4	3.9	10.9	2.5	6.0	66.3	.09	.20
Linseed meal:								
33-38 percent protein	8.5	5.6	35.3	5.4	8.3	36.9	.36	.84
38-43 percent protein	8.5	5.3	40.4	5.8	7.5	32.5	.33	.74
Malt	7.7	2.9	12.4	2.1	6.0	68.9	...	...
Malt sprouts	7.3	6.1	28.1	1.8	13.3	43.4	.26	.68
Mesquite beans and pods	6.6	4.5	13.0	2.7	22.8	50.4	...	...
Millet, foxtail	10.1	3.3	12.6	4.3	8.4	61.3	...	...
Millet, proso or hog millet	9.8	3.4	12.0	3.4	7.9	63.5	...	...
Milo	9.3	1.6	12.5	3.2	1.5	71.9	...	...
Milo-head chops	10.4	4.3	10.7	2.6	7.1	64.9	...	...
Molasses, cane	24.0	6.8	3.1	...	...	66.1	.35	.06
Oats, grain	7.7	3.5	12.5	4.4	11.2	60.7	.10	.40
Oat chops	8.9	3.9	12.8	5.0	11.8	57.6	.10	.36
Oat clips	9.0	9.3	11.8	4.5	22.7	42.7	...	...
Oat groats, ground rolled	10.4	2.6	17.3	6.6	1.8	61.3	.08	.43
Oat hulls	5.8	6.5	4.3	1.9	30.8	50.7	.09	.12
Oatmeal	8.9	2.3	16.5	4.8	3.6	63.9	.08	.43
Oat millfeed	6.9	6.0	6.3	2.2	27.9	50.7	.20	.22
Palm kernel	8.4	1.8	8.4	48.8	5.8	26.8	...	...
Palm-kernel cake	10.1	3.9	16.2	11.0	21.4	37.4	...	...

[1] Fat.

[2] Carbohydrates except fiber.

[3] Leaders indicate that data are lacking.

TABLE 1.—*The percentage composition of feedstuffs used in animal feeding*—Continued

GRAINS, SEEDS, AND MILL CONCENTRATES—Continued

Feedstuff	Moisture	Ash	Crude protein	Ether extract	Crude fiber	Nitrogen-free extract	Calcium	Phosphorus
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Peanuts, kernels	5.5	2.3	30.2	47.6	2.8	11.6	0.06	0.38
Peanuts, shells on	6.0	2.8	24.7	38.1	18.0	15.4		
Peanut meal:								
38–43 percent protein	6.4	4.4	41.6	7.2	16.0	24.4	.10	.50
43–48 percent protein	6.7	4.6	45.1	7.2	14.2	22.2	.17	.55
Over 48 percent protein	7.0	5.0	51.4	4.8	9.2	22.6		
Rapeseed, brown Indian	5.7	6.4	21.0	41.2	12.5	13.2		
Rapeseed, common	7.3	4.2	19.5	45.0	6.0	18.0		
Rice, rough	9.7	5.4	7.3	2.0	8.6	67.0	.10	.10
Rice, bran	8.8	12.2	12.8	13.8	12.2	40.2	.10	1.84
Rice hulls	6.5	21.9	2.1	.4	44.8	24.3	.08	.06
Rice polish	10.0	7.6	12.4	13.2	2.8	54.0	.03	1.52
Rice-stone bran	8.4	11.9	12.5	13.0	11.1	43.1		
Rye	9.5	1.9	11.1	1.7	2.1	73.7	.04	.37
Rye feed	10.2	4.0	15.6	3.2	4.3	62.7		.59
Rye middlings	9.5	4.4	16.7	3.7	5.5	60.2		
Sesame seed	5.5	6.5	20.3	45.6	7.1	15.0		
Sesame-seed cake	9.8	10.7	37.5	14.0	6.3	21.7		
Sorgo	12.8	2.1	9.1	3.6	2.6	69.8		
Soybeans	8.0	4.8	38.9	18.0	4.8	25.5	.22	.67
Soybean meal:								
38–43 percent protein	7.8	5.8	41.7	5.8	6.2	32.7	.29	.67
43–48 percent protein	8.2	6.0	44.7	4.6	5.8	30.7	.34	.71
Sunflower seed	6.9	3.2	15.2	28.8	28.5	17.4		
Sunflower hulls	10.5	2.6	4.4	3.4	57.0	22.1		
Sunflower kernels	6.9	4.2	29.4	43.9	2.6	13.0		
Velvetbeans	9.8	3.1	26.2	4.8	6.0	50.1		
Vinegar grains	6.8	2.9	19.5	7.0	17.3	46.5		
Wheat	10.6	1.8	12.0	2.0	2.0	71.6	.05	.38
Wheat bran	9.4	6.4	16.4	4.4	9.9	53.5	.10	1.14
Wheat, brown shorts	10.8	4.0	17.8	4.8	5.8	56.8		
Wheat-flour middlings	10.4	3.3	18.8	4.0	4.2	59.3	.09	.80
Wheat, gray shorts	11.0	4.1	17.5	4.4	5.4	57.6	.08	.86
Wheat, mixed feed	9.9	4.4	18.2	4.4	6.9	56.1	.11	.96
Wheat, red dog	11.1	2.2	18.3	3.4	2.3	62.7	.12	.83
Wheat, standard middlings	10.4	3.9	17.0	4.3	5.4	59.0	.09	.90
Wheat, white shorts	10.9	2.2	15.6	3.7	2.4	65.2		
Wheat waste, shredded	8.0	1.6	12.4	1.6	2.6	73.8		
Yeast cells, dried	4.3	10.7	48.5	.5	.5	35.5	.42	1.90

ANIMAL, MARINE, AND MILK PRODUCTS

Feedstuff	Moisture	Ash	Crude protein	Ether extract	Crude fiber	Nitrogen-free extract	Calcium	Phosphorus
Beef meal	8.0	13.0	70.6	9.1	0	0		
Blood meal	14.4	4.7	78.4	.6	0.8	1.1	0.35	0.24
Bone, green, horse	59.0	20.4	19.2	.4	0	0		
Bone, green, butchershop	52.0	16.3	16.6	17.0	0	0		
Bonemeal, raw	6.7	62.1	25.2	3.3	1.4	1.3	24.2	11.5
Bonemeal, steamed	3.1	83.6	6.2	2.2	1.3	3.6	30.0	13.9
Bonemeal, special steamed	2.7	75.1	11.1	6.5	1.7	2.9	27.0	13.2
Buttermilk	91.0	.7	3.0	.5		4.8	.13	.09
Buttermilk, dried	5.5	9.4	34.3	7.0	.3	43.5	1.32	.93
Crab meal	8.4	37.1	37.9	3.1	8.4	5.1		
Fish meal	7.1	17.7	62.0	7.3	.6	5.3	4.31	2.68
Fish meal, menhaden	7.1	25.7	57.8	6.2	2.4	.8		
Fish meal, sardine	6.7	13.4	68.1	4.3	.5	7.0		
Fish, whiting	71.0	5.4	18.8	4.0	1.7	0		
Lips, ox	71.0	1.5	19.0	9.5	0	0		
Liver, hog	72.8		19.8	5.3	0	0		
Liver meal	6.4	7.5	67.2	14.6	1.9	2.4		
Lungs, beef	79.7	1.0	16.1	3.2	0	0		
Lungs, calf	76.8	1.1	16.1	5.0	0	0		
Meat, horse muscle	75.0	1.1	20.2	2.9	0	0		
Meat, beef muscle	72.0	1.0	21.2	5.2	0	0		
Meat and bone scraps:								
42–48 percent protein	6.1	31.6	46.8	11.8	2.1	1.6	11.2	5.06
48–53 percent protein	6.4	30.5	50.4	9.7	2.0	1.0	10.5	5.21
53–58 percent protein	6.1	25.5	54.9	11.1	2.1	.3	8.26	4.02
Meat scraps:								
48–53 percent protein	5.7	28.0	51.0	12.0	1.6	1.7		
53–58 percent protein	6.3	26.7	55.0	9.1	2.2	.7	8.70	1.30
Melts, beef	75.0	1.5	19.0	2.0	0	0		
Melts, pork	78.0	1.5	17.5	2.0	0	0		

Table 1.—*The percentage composition of feedstuffs used in animal feeding*—Continued

ANIMAL, MARINE, AND MILK PRODUCTS—Continued

Feedstuff	Moisture	Ash	Crude protein	Ether extract	Crude fiber	Nitrogen-free extract	Calcium	Phosphorus
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Milk, skim	91.1	0.8	3.4	0.2	0	4.5	0.13	0.10
Milk, skim, dried	4.7	8.8	35.8	1.0	.1	49.6	1.34	.99
Milk, whole	87.1	.7	3.6	3.7	0	4.9	.12	.09
Shrimp meal	10.7	33.4	38.5	2.6	11.7	3.1	7.71	1.31
Tankage, digester:								
53–58 percent protein	7.6	21.8	55.8	10.4	2.5	1.9	8.92	4.22
Over 58 percent protein	6.8	19.5	61.6	8.6	1.7	1.8	7.07	3.72
Tankage, digester with bone:								
38–43 percent protein	6.4	32.4	40.0	14.1	3.0	4.1	------	------
43-48 percent protein	6.3	31.3	46.0	12.5	1.9	2.0	------	------
48-53 percent protein	5.8	28.6	51.2	10.4	1.6	2.4	------	------
Over 53 percent protein	6.2	24.2	54.5	10.3	1.7	3.1	9.24	4.15
Tripe, raw	86.5	.3	11.7	1.2	0	.3	------	------
Viscera, horse (includes blood)	77.0	1.1	19.8	1.2	0	0	------	------
Whey	93.8	.4	.6	1	0	5.1	.04	.04
Whey, dried	6.7	10.1	12.8	.6	.2	69.6	.73	.66

GREEN FORAGES

Feedstuff	Moisture	Ash	Crude protein	Ether extract	Crude fiber	Nitrogen-free extract	Calcium	Phosphorus
Alfalfa, immature	79.4	2.9	5.2	0.7	3.8	8.0	0.28	0.09
Alfalfa, in bloom	77.2	1.8	3.2	.6	7.8	9.4	.39	.07
Alsike clover, immature	81.2	2.4	4.9	.6	3.1	7.8	.26	.09
Alsike clover, in bloom	74.8	2.0	3.9	.9	7.4	11.0	.21	.06
Barley, immature	83.4	1.5	2.8	.7	3.6	8.0	.06	.07
Barley, mature	77.1	1.6	2.2	.5	6.4	12.2	.05	.07
Bluegrass, Kentucky, immature	70.5	2.5	5.0	1.2	7.5	13.3	.15	.13
Bromegrass, immature	77.5	2.9	4.3	.9	5.2	9.2	.14	.10
Cabbage	90.5	.9	2.4	.3	1.2	4.7	.06	.02
Canada bluegrass, immature	74.1	2.5	4.3	1.3	6.8	11.0	.11	.12
Corn fodder:								
Dent, immature	79.0	1.2	1.7	.5	5.6	12.0	------	------
Dent, mature	73.4	1.5	2.0	.9	6.7	15.5	------	------
Flint, immature	79.8	1.1	2.0	.7	4.3	12.1	------	------
Flint, mature	77.1	1.1	2.1	.8	4.3	14.6	------	------
Cowpeas	82.5	2.5	3.4	.5	4.0	7.1	.18	.05
Crimson clover	80.9	1.7	3.1	.7	5.2	8.4	.28	.04
Kafir	73.0	2.0	2.3	.7	6.9	15.1	------	------
Lespedeza, Korean, immature	74.1	2.4	4.6	.8	5.8	12.3	.34	.11
Meadow fescue, immature	78.8	2.6	4.0	.9	4.7	9.0	.15	.11
Meadow foxtail, immature	73.9	2.8	4.5	1.2	5.6	12.0	.15	.12
Millet, foxtail	71.1	1.7	3.1	.7	9.2	14.2	.09	.05
Oatgrass, tall, immature	78.4	3.0	4.3	1.0	4.6	8.7	.11	.13
Oats, immature	82.6	1.7	2.9	.7	3.3	8.8	.07	.07
Oats, mature	72.0	2.1	2.7	.9	7.4	14.9	.08	.08
Orchard grass, immature	78.3	2.8	3.4	1.0	5.3	9.2	.14	.13
Orchard grass, in bloom	73.0	2.0	2.6	.9	8.2	13.3	------	------
Pricklypear	78.9	4.3	.7	.4	2.6	13.1	------	------
Rape	85.7	2.0	2.4	.6	2.2	7.1	------	------
Red clover, immature	81.2	2.7	5.0	.8	3.0	7.3	.27	.10
Red clover, in bloom	70.8	2.1	4.4	1.1	8.1	13.5	.14	.07
Red fescue, immature	70.5	2.8	4.1	.9	8.2	13.5	.16	.13
Red top, immature	76.8	2.8	4.1	.9	5.4	10.0	.15	.10
Reed canary grass, immature	80.7	2.4	3.5	.7	4.3	8.4	.13	.10
Rye, immature	80.8	2.3	4.5	1.1	3.4	7.9	.10	.10
Rye, mature	76.6	1.8	2.6	.6	11.6	6.8	.08	.06
Rye grass, Italian, immature	77.3	2.5	3.5	1.0	5.2	10.5	.13	.12
Rye grass, perennial, immature	75.9	3.0	3.8	.9	5.4	11.0	.15	.12
Sorgo	77.3	1.3	1.5	1.0	6.2	12.7	------	------
Soybeans	73.9	2.9	4.0	1.1	7.6	10.5	.28	.05
Sweetclover, immature	75.3	2.2	5.3	.7	6.7	9.8	.26	.07
Sweet corn	79.1	1.3	1.9	.5	4.4	12.8	------	------
Timothy, immature	74.9	2.3	4.1	.9	5.4	12.4	.12	.11
Timothy, in bloom	61.6	2.1	3.1	1.2	11.8	20.2	.13	.05
Wheat, immature	82.3	2.1	3.8	.9	3.0	7.9	.07	.10
Wheat, mature	68.7	2.6	2.4	.7	8.6	17.0	.06	.08
White clover, immature	82.0	2.1	4.9	.6	3.1	7.3	.23	.09
White clover, wild, immature	81.2	2.2	5.2	.6	2.9	7.9	.25	.10

TABLE 1.—*The percentage composition of feedstuffs used in animal feeding*—Continued

DRIED FORAGES

Feedstuff	Moisture	Ash	Crude protein	Ether extract	Crude fiber	Nitrogen-free extract	Calcium	Phosphorus
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Alfalfa hay	7.2	8.0	15.4	1.6	30.3	37.5	1.51	0.21
Alfalfa-leaf meal	8.5	14.4	20.9	2.6	15.7	37.9	1.42	.25
Alfalfa meal	8.2	10.0	15.2	2.2	27.5	36.9	1.56	.22
Alfalfa meal, dehydrated	6.6	10.0	16.9	2.6	25.4	38.5	----	----
Alfalfa-stem meal	9.1	7.7	11.4	1.3	36.1	34.4	----	----
Alsike clover hay	10.5	8.8	14.4	2.5	24.7	39.1	.78	.20
Australian saltbush hay	6.7	16.9	16.1	1.8	21.5	37.0	----	----
Barley hay	15.0	6.4	6.7	1.6	21.4	48.9	.17	.25
Barley straw	14.2	5.7	3.5	1.5	36.0	39.1	----	----
Bermuda grass hay	8.9	7.9	7.2	1.7	24.9	49.4	.60	.16
Black grama hay	5.5	7.0	4.3	1.3	31.4	50.5	.22	.09
Blue grama hay	10.9	8.5	6.7	1.8	27.9	44.2	----	----
Bluegrass hay, immature	7.3	7.9	15.2	3.0	23.7	42.9	.45	.35
Bluegrass hay, bloom	11.9	7.0	9.3	3.4	27.9	40.5	.30	.21
Bluejoint grass hay	7.5	6.9	6.7	3.0	34.2	41.7	----	----
Bromegrass hay	14.0	9.7	9.3	1.8	26.6	38.6	----	----
Buckwheat straw	9.9	5.5	5.2	1.3	43.0	35.1	----	----
Buffalo grass hay	6.2	10.8	5.6	1.7	26.1	49.6	----	----
Bur-clover hay	8.7	12.3	15.7	3.0	25.5	34.8	1.11	.15
Corncobs	10.7	1.4	2.4	.5	30.1	54.9	----	----
Corn fodder	11.8	5.8	7.4	2.4	23.0	49.6		----
Corn husks	9.8	2.9	2.9	.7	30.7	53.0	----	----
Corn leaves	11.8	8.5	8.1	2.2	24.4	45.0	----	----
Cornstalks	11.7	4.6	4.8	1.8	32.7	44.4	----	----
Corn stover	10.7	6.1	5.7	1.5	30.3	45.7	.45	.10
Cowpea hay	9.7	12.9	17.5	2.8	20.5	36.6	1.84	.25
Cowpea straw	9.7	5.3	7.4	1.3	41.5	34.8	----	----
Crabgrass hay	9.0	7.9	6.5	2.2	32.1	42.3	.33	.17
Crimson clover hay	9.6	8.6	15.2	2.8	27.2	36.6	1.18	.13
Feterita fodder	13.3	6.4	8.7	1.9	21.5	48.2	.27	.19
Field-pea hay	10.6	8.3	16.1	2.7	24.8	37.5	----	----
Flax straw	6.2	3.8	7.8	2.1	46.9	33.2	----	----
Hegari fodder	13.5	8.2	6.2	1.7	16.7	53.7	.17	.18
Hegari stover	15.1	9.7	4.5	1.9	26.6	42.2	.38	.09
Johnson grass hay	7.2	7.2	8.1	2.8	30.4	44.3	.55	.40
Kafir fodder	9.1	7.8	6.6	2.1	28.4	46.0	.31	.05
Kafir stover	12.6	9.0	5.8	1.7	27.5	43.4	----	----
Lespedeza hay	7.9	6.2	11.9	2.8	28.5	42.7	.80	.25
Little bluestem hay	8.6	4.9	4.0	1.6	35.4	45.5	----	----
Meadow fescue hay	11.6	7.0	6.6	2.0	31.6	41.2	----	----
Millet hay, foxtail	7.0	8.2	9.2	2.8	28.0	44.8	----	
Millet hay, pearl or cattail	10.1	9.7	9.0	1.8	32.3	37.1	----	
Natal grass hay	7.5	4.8	3.7	1.4	39.5	43.1	.49	.32
Oatgrass, tall, hay	8.1	6.4	9.4	2.7	29.8	43.6	----	
Oat hay	11.8	5.7	6.1	2.4	27.1	46.9	.27	.22
Oat straw	8.1	7.6	4.4	2.5	36.2	41.2	.23	.20
Orchard grass hay, immature	9.9	6.0	8.1	2.6	32.4	41.0	.31	.18
Orchard grass hay, mature	9.9	7.0	6.9	3.0	32.7	40.5	----	
Prairie hay (Colorado, Wyoming)	5.5	7.2	7.0	2.4	31.3	46.6	----	----
Prairie hay (Kansas, Oklahoma)	9.5	7.5	4.4	2.3	30.4	45.9	.55	.07
Prairie hay (Minnesota, South Dakota)	11.6	7.2	6.0	2.4	30.3	42.5	.44	.11
Red clover hay	7.0	10.0	16.1	2.6	23.6	40.7	1.01	.14
Red clover, mammoth, hay	12.2	7.5	12.8	3.3	27.1	37.1	----	
Red top hay	8.9	5.2	7.9	1.9	28.6	47.5	.35	.18
Rhodes grass hay	8.6	8.4	5.3	1.2	33.4	43.1	----	----
Rice straw	8.9	13.5	4.5	1.6	34.0	37.5	.18	.05
Rye hay	6.4	4.7	5.9	2.0	37.4	43.6	.27	.22
Rye straw	7.1	3.2	3.0	1.2	38.9	46.6	----	
Rye grass, perennial, hay	10.2	8.6	8.6	4.1	24.5	44.0	.17	.11
Rye grass, Italian, hay	8.5	6.9	7.5	1.7	30.5	44.9	----	----
Rye grass hay	8.3	8.5	6.3	2.0	33.0	41.9	----	----
Sedge, western species	5.4	6.7	11.6	2.4	27.4	46.5	----	----
Slender wheatgrass	7.5	6.6	7.8	2.1	30.8	45.2	----	----
Sorgo fodder	11.6	6.0	5.3	2.4	26.0	48.7	.27	.15
Sorgo hay	5.8	9.5	9.5	1.9	26.8	46.5	.31	.09
Soybean hay	8.4	8.9	15.8	3.8	24.3	38.8	1.26	.22
Soybean straw	8.7	7.4	5.7	2.5	34.6	41.1	----	
Sudan grass hay	5.3	8.1	9.7	1.7	27.9	47.3	.47	.24
Sweetclover hay	8.1	7.5	16.2	2.8	25.9	39.5	.74	.08
Sweetclover straw	5.1	3.4	6.7	1.2	49.6	34.0	----	----
Timothy hay	7.1	5.8	7.5	2.9	30.2	46.5	.31	.13
Vetch, hairy, hay	13.1	8.4	20.9	2.7	24.2	30.7	.25	.30
Western needlegrass hay	9.9	6.2	5.5	2.7	33.2	42.5	----	----
Wes[illegible]tgrass hay	8.6	8.7	8.4	2.8	31.9	40.1	----	----

TABLE 1.—*The percentage compositon of feedstuffs used in animal feeding*—Continued

DRIED FORAGES—Continued

Feedstuff	Moisture	Ash	Crude protein	Ether extract	Crude fiber	Nitrogen-free extract	Calcium	Phosphorus
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Wheat hay	9.6	4.2	3.4	1.3	38.1	43.4	0.14	0.15
Wheat straw	6.8	5.4	4.3	3.4	36.8	43.3		
White clover hay	7.2	9.4	15.6	2.2	22.7	42.9	1.31	.28
Wire grass hay	8.5	7.3	6.6	1.3	34.6	41.7		

SILAGES, ROOTS, TUBERS, AND BYPRODUCTS

Feedstuff	Moisture	Ash	Crude protein	Ether extract	Crude fiber	Nitrogen-free extract	Calcium	Phosphorus
Alfalfa silage	68.9	2.7	5.7	1.0	8.8	12.9		
Alfalfa-molasses silage	68.6	3.4	5.8	1.0	8.4	12.8		
Apple pomace	78.6	.6	1.3	1.2	3.7	14.6	0.02	0.01
Apple silage	87.6	.6	.7	.7	1.8	8.6		
Beet pulp, dried	9.2	3.2	9.3	.8	20.0	57.5	.66	.06
Beet pulp, molasses, dried	8.0	5.2	11.6	.7	16.4	58.1	.59	.09
Carrots	88.6	1.0	1.1	.4	1.3	7.6		
Cassava	63.8	1.4	1.0	.3	.8	32.7		
Corn silage	73.8	1.7	2.1	.8	6.3	15.3	.08	.08
Corn silage, immature	79.1	1.4	1.7	.8	6.0	11.0		
Corn silage, mature	70.9	1.4	2.4	.9	6.9	17.5		
Corn stover silage	80.7	1.8	1.8	.6	5.6	9.5		
Cowpea silage	77.8	2.1	3.2	.9	6.5	9.5		
Hegari silage	66.3	3.4	2.3	.8	6.7	20.5		
Jerusalem artichokes	78.7	1.1	2.5	.2	.8	16.7		
Mangel-wurzel	90.8	1.0	1.4	.2	.9	5.7	.02	.02
Napier grass silage	67.5	1.8	1.2	.7	14.4	14.4	10	10
Parsnips	80.0	1.3	2.2	.4	1.3	14.8		
Pea-vine silage	75.1	1.7	3.0	.9	8.1	11.2		
Potatoes	78.9	1.0	2.1	.1	.6	17.3	.01	.06
Red clover silage	72.0	2.6	4.2	1.2	8.4	11.6		
Rutabagas	88.6	1.2	1.2	.2	1.3	7.5	.05	.04
Sorgo silage	74.7	1.4	1.6	1.0	6.9	14.4	.09	.04
Soybean silage	75.6	2.6	2.4	.8	9.6	9.0	.29	.10
Sugar beets	78.0	1.0	1.5	.1	2.9	16.5	.05	.06
Sugar-beet pulp	90.5	.4	.9	.2	2.2	5.8		
Sunflower silage	77.9	2.1	1.8	1.6	6.5	10.1		
Sweetclover silage	70.2	2.9	6.1	1.0	9.7	10.1		
Sweetpotatoes	71.1	1.0	1.5	.4	1.3	24.7	.02	.05
Turnips	90.6	.8	1.3	.2	1.2	5.9	.05	.05

TABLE 2. *The digestible protein and total digestible nutrient content of feedstuffs as determined for cattle, sheep, and swine*

GRAINS, SEEDS, AND MILL CONCENTRATES

Feedstuff	Digestible protein			Total digestible nutrients		
	Cattle	Sheep	Swine	Cattle	Sheep	Swine
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Barley		10.0	9.6		77.1	74.3
Barley feed		13.2	14.3		81.2	83.3
Brewers' dried grains:						
18-23 percent protein	15.5	16.3	15.1	68.3	65.0	48.5
23-28 percent protein		20.8			71.9	
Buckwheat		7.2	7.2		62.2	68.5
Buckwheat middlings	25.5	23.8		77.3	73.7	
Cocoa shells		2.0			55.5	
Coconut cake			14.1			84.9
Coconut meal, old process		17.5			83.8	
Corn, shelled	5.2	7.5	7.2	78.3	73.9	80.0
Corn bran	5.2	5.3		59.9	72.9	
Corn chop			7.7			82.0
Corn, ear, chop	4.8	5.7	6.2	68.6	75.6	70.2
Corn-feed meal			7.9			80.6
Corn-gluten feed		23.2			77.9	
Corn-gluten meal		37.8			78.4	
Corn-oil meal		17.0			80.8	
Cottonseed, whole pressed	15.1	21.6		57.1	64.2	
Cottonseed feed		27.3			79.7	
Cottonseed hulls	.5			35.7	24.8	

TABLE 2.—*The digestible protein and total digestible nutrient content of feedstuffs as determined for cattle, sheep, and swine*—Continued

GRAINS, SEEDS, AND MILL CONCENTRATES—Continued

Feedstuff	Digestible protein			Total digestible nutrients		
	Cattle	Sheep	Swine	Cattle	Sheep	Swine
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Cottonseed meal:						
33–38 percent protein	31.5	28.2	31.1	63.6	65.7	67.1
38–43 percent protein	35.3	31.6	34.9	66.7	68.0	69.8
Over 43 percent protein	37.6	33.6	37.1	67.9	68.7	70.8
Distillers' (corn) dried grain		20.1			81.6	
Feterita		10.9			81.0	
Hominy feed		8.2			88.3	
Kafir	9.0	7.1	8.5	79.7	70.9	81.4
Kafir head chops		6.9			67.8	
Linseed meal:						
33–38 percent protein		29.7	31.4		76.0	71.6
38–43 percent protein		33.9	36.0		77.0	73.1
Malt sprouts		21.7			71.2	
Mesquite beans, pods on		11.7			71.9	
Millet, proso or hog millet		7.3	8.2		69.2	73.7
Milo	8.3	9.5	7.6	75.9	85.6	72.7
Milo head chops		8.1			76.0	
Molasses	.2	.8		57.0	62.3	
Oats, grain	9.1	9.4	9.9	72.3	76.0	74.3
Oat clips		4.7			52.0	
Oat groats, ground rolled		15.6			91.4	
Oat hulls	2.2	.7	2.5	58.7	42.5	25.0
Oat millfeed		4.2			48.2	
Palm-kernel cake			11.3			67.1
Peanuts (shells on)		20.0			97.4	
Peanut meal:						
38–43 percent protein		37.0			78.8	
43–48 percent protein		40.1			79.4	
Over 48 percent protein		45.7			78.3	
Rice, rough		5.5			70.7	
Rice, bran	8.3	8.8	8.6	58.4	67.5	65.9
Rice hulls		.1			8.0	
Rice polish	8.2	8.8	10.3	81.0	85.6	89.1
Rye		9.3			[1] 79.6	
Rye feed		11.5	13.4		68.3	77.7
Sesame seed cake		34.5			84.1	
Sorgo	4.5	4.7	5.5	71.8	64.6	[1] 69.3
Soybeans	35.0	35.0	36.6	92.3	90.0	97.8
Soybean meal:						
38–43 percent protein		37.5			77.4	
43–48 percent protein		40.2			76.2	
Sunflower seed		10.6			77.4	
Velvetbeans		19.4			74.0	
Vinegar grains		12.5			62.3	
Wheat		9.1	9.1		75.9	73.0
Wheat bran	12.6	12.5	12.5	63.3	61.1	57.9
Wheat, brown shorts		14.6			64.8	
Wheat, flour middlings	13.7	16.2	15.6	72.4	78.8	[1] 71.7
Wheat, mixed feed	14.3	13.9	13.5		57.4	[1] 64.9
Wheat, red dog			16.5			[1] 76.3
Wheat, standard middlings		12.9	13.9		66.8	58.8
Wheat, white shorts		14.3	11.5		87.0	[2] 69.1
Wheat waste, shredded	8.2	9.1	9.4	70.7	65.1	69.9

ANIMAL, MARINE, AND MILK PRODUCTS

Feedstuff	Digestible protein			Total digestible nutrients		
	Cattle	Sheep	Swine	Cattle	Sheep	Swine
Blood meal		65.9				
Fish meal		46.5	57.0		62.9	64.4
Fish meal, menhaden		46.8			60.8	
Meat and bone scraps:						
42–48 percent protein			46.3			[1] 72.9
48–53 percent protein			49.9			[1] 71.7
53–58 percent protein			54.4			[1] 79.7
Milk, whole	3.3		3.4	11.3		16.2
Milk, skim	3.2	3.2	3.2	7.8	7.9	7.8
Tankage, digested:						
53–58 percent protein			39.1			61.8
Over 58 percent protein		23.4	51.1		46.1	70.1

[1] Crude fiber not included in calculation.

[2] No fat.

TABLE 2.—*The digestible protein and total digestible nutrient content of feedstuffs as determined for cattle, sheep, and swine*—Continued

GREEN FORAGES

Feedstuff	Digestible protein			Total digestible nutrients		
	Cattle	Sheep	Swine	Cattle	Sheep	Swine
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Alfalfa, immature	3.8			11.8		
Barley, immature		2.0			10.8	
Bromegrass, immature		2.9			9.6	
Cabbage		2.1			7.2	
Corn fodder, dent	1.1	1.1		11.2	14.4	
Cowpeas		2.6			11.0	
Crimson clover		2.4			9.8	
Millet, foxtail		2.1			19.5	
Prickly pear	.3	.4		12.4	11.4	
Rape		2.1			11.2	
Red clover, in bloom	2.9		1.9	19.3		13.0
Rye	2.1			17.0		
Soybeans	3.2			16.0		
Sweetclover, immature		4.1			15.7	
Sweet corn		1.2			15.1	
Timothy, immature	2.0			14.3		
White clover, immature		3.6			11.2	

DRIED FORAGES

Feedstuff	Digestible protein			Total digestible nutrients		
	Cattle	Sheep	Swine	Cattle	Sheep	Swine
Alfalfa hay		11.7	7.9		54.4	38.6
Alfalfa meal	11.2	9.7		49.6	50.1	
Alsike clover hay	9.5			53.4		
Australian saltbush hay		13.7			44.2	
Barley hay		4.4			50.0	
Bermuda grass hay		3.7			44.3	
Bluegrass hay		5.6			50.2	
Bluejoint grass hay		4.2			47.0	
Bromegrass hay		5.1			47.7	
Buffalo grass hay	3.0	3.0		53.2	48.3	
Bur-clover hay		10.8			49.2	
Corncobs		.1			45.5	
Corn fodder	3.4			54.4		
Corn husks	.8	.4		65.6	54.5	
Corn stover	2.5	2.1		53.4	49.8	
Cowpea hay		12.1			47.9	
Crabgrass hay		2.0			46.6	
Crimson clover hay	10.3	10.5		51.4	49.2	
Field-pea hay		12.9			57.5	
Flax straw		6.3			37.5	
Johnson grass hay		3.6			53.2	
Kafir fodder	2.5	3.4		52.8	54.3	
Kafir stover	2.3	2.4		50.2	45.9	
Meadow fescue hay		3.1			50.3	
Millet hay, pearl or cattail		5.8			55.1	
Natal grass hay	.4			47.8		
Oatgrass, tall, hay		4.4			49.1	
Oat hay		3.3			48.1	
Oat straw	1.5	.5		45.5	39.4	
Orchard grass hay	4.9	4.3		52.4	50.1	
Prairie hay (Kansas, Oklahoma)	.8			50.3		
Prairie hay (Minnesota, South Dakota)		2.2			44.1	
Red clover hay	9.7	9.5		49.6	50.0	
Red top hay		4.8			53.9	
Rhodes grass hay	2.7	2.4		49.7	53.1	
Rice straw		1.0			39.1	
Rye grass hay, Italian		2.7			56.0	
Sorgo fodder	3.3	1.7		60.2	49.4	
Soybean hay	11.2	11.4		55.6	51.3	
Soybean straw		.9			35.0	
Sudan grass hay	3.4	5.0		53.5	49.0	
Sweetclover hay		12.3			51.5	
Timothy hay	3.5	3.3		52.5	53.5	
Vetch, hairy, hay	13.8	15.0		58.9	52.6	
Western wheatgrass hay		4.4			52.6	
Wire grass hay		3.2			51.0	

TABLE 2.—*The digestible protein and total digestible nutrient content of feedstuffs as determined for cattle, sheep, and swine*—Continued

SILAGES, ROOTS, TUBERS, AND BYPRODUCTS

Feedstuff	Digestible protein			Total digestible nutrients		
	Cattle	Sheep	Swine	Cattle	Sheep	Swine
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Alfalfa silage	4.0	3.1		18.8	13.8	
Alfalfa-molasses silage	4.0			18.8		
Apple pomace	.3			14.3	15.3	
Beet pulp, dried		5.3	3.0		73.9	70.8
Beet pulp, molasses, dried	7.7			69.3		
Carrots	.8	.8		10.4	9.4	
Cassava	.2			19.6		
Corn silage	1.0	1.1		17.5	17.4	
Corn-stover silage	.7	.9		10.4	10.1	
Cowpea silage	1.9			13.5		
Mangel-wurzel	.7	.8		6.6	6.9	
Napier grass silage	.3			14.3		
Pea-vine silage		1.6			14.3	
Potatoes	.7	.9	.9	17.0	16.6	17.3
Red clover silage	1.3	1.7		10.4	14.3	
Rutabagas		1.0			9.5	
Sorgo silage		.4			16.1	
Soybean silage	1.6			13.2		
Sugar beets		1.4			20.9	
Sunflower silage	1.0	.8		12.6	14.1	
Sweetclover silage	4.6	4.7		17.6	16.2	
Turnips	.8	1.1		7.8	7.9	

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INDEX

Page

- A. I. V. solution, use in making silage 1009–1010
- Acidity—
  - effect on silage 1011–1012
  - in silages, causes and effects 983–984
- Acids, additions to silage, purposes 987–988
- ADAMS, GEORGIAN: Food Composition. With Charlotte Chatfield 272–285
- Adrenal glands, effect on milk secretion 692
- Advertising—
  - food—
    - ethical and unethical methods 140
    - misleading attacks on 144
- Agricultural adjustment programs—
  - goals 397–400
  - relation to nutritional goal. J. P. Cavin 396–402
- Agricultural Research Center—
  - swine nutrition tests 706–708, 714
  - swine-performance tests 714
- Agriculture, role in attaining nutritional goal 400–402
- Alfalfa—
  - green—
    - curing, amounts saved or lost 994
    - dry matter and protein content per ton 993
  - protein and fiber content of leaf and stem at different growth stages 960
  - stems and leaves, composition and digestibility 960
- Aluminum, occurrence in food 216
- American Medical Association, Council on Pharmacy and Chemistry, recommendations of cod-liver oil dosage 258
- Amino acids—
  - content of feeds, value in protein calculation 658–659
  - dietary essentials 177
  - formation of proteins 17
  - function in synthesis of body proteins 695–696
  - origin, characteristics, and classification 175–178
- Ammonia, formation in silage 1006
- Amylase, function in digestion 429
- Amylopsin, function in digestion 427
- Anemia—
  - in children, occurrence and control 200–203, 209
  - in women, occurrence and control 206–207, 209–210
  - milk, in pigs, prevention and cure, recommendations 516
  - relation to copper content of blood 209
- Animal—
  - food transformation into heat and energy 436–438
  - nutrition 405–1142
  - nutrition—
    - summary 44–94
    - educational needs 1048–1050
    - plane, relation to reproduction 482–485
    - relation to reproduction and vitamin requirements 485–487
    - research, broad view 1046–1048
  - products—
    - digestible protein and digestible nutrient content for cattle, sheep, and swine, determinations 1072
    - feed value 1023–1024
    - percentage composition used in animal feeding 1068–1069
    - vitamin value, relation to feeding practices and breed 292
  - yields, correlation with forage yields, research 954–955
- Animals—
  - breeding experiments 478–479
  - carnivorous, digestive tract, adaptation to type of diet 418–419

Animals—Continued. Page

  - dietary requirements for reproduction 482
  - domestic—
    - chewing, description and comparison 422–423
    - digestion in, description and comparison 424–429
    - digestive processes. H. W. Schoening 418–430
    - digestive processes, summary 45–47
    - food absorption in 429–430
    - prehension, description and comparison 419–421
    - salivary secretion and swallowing, description and comparison 423–424
  - economic or practical maintenance requirements, measurement 448–449
  - farm—
    - body processes, maintenance 433–443
    - control of body temperature, factors affecting 433–434
    - factors affecting maintenance nutrition, feed utilization, and health. Louis L. Madsen 431–449
    - feed utilization, effect of dietary deficiencies 438–443
    - food requirements 431–433
    - growth, fattening, and meat production. O. G. Hankins and Harry W. Titus 450–468
    - health, effect of dietary deficiencies 438–443
    - heat production, effects of foods 434–436
    - idle, wintering 782–783
    - nutrition, feed, and health, factors affecting, summary 47–48
    - nutritional requirements for particular function, suggested research 1054–1055
    - nutritional requirements, meager knowledge relating to 1052–1054
    - overfeeding, results 443–446
    - undernutrition, effects 446–448
  - feeds and feeding regimes affecting specific kinds and types, suggestions for research 1059–1064
  - fur, nutrition—
    - Charles E. Kellogg 871–892
    - summary 84–86
  - gastrointestinal canal, relative capacity 847
  - growth—
    - and development, mineral elements necessary 409–410
    - changes 450–453
    - relation to feed utilization, measuring the efficiency 465–567
  - health, chemical compounds necessary 578–587
  - heat, energy, and protein requirements 436–438
  - herbivorous, digestive tract, adaptation to type of diet 418–419
  - immaturity, influence on nutritional requirements 502–503
  - longevity, relation to nutrition 475
  - manufacture of vitamin A 222, 224
  - meat—
    - chemical composition 458–460
    - composition, estimation 467–468
    - growth and fattening, effects 453–458
    - nutrition and longevity 475
    - nutritional levels, significance 469–475
    - undernutrition and exercise, effects 474–475
    - weight and feed correlations 465–468
  - mineral requirement 529–530
  - omnivorous, digestive tract, adaptation to type of diet 418–419
  - phosphorus deficiency, effects 441–442
  - proportion of edible meat 462–464
  - reproduction, relation to diet, summary 50–52
  - suckling—
    - feeding, practical points 509–518
    - food requirements 501–518

Page

- Animals—Continued.
  - very young—
    - immunity to infectious diseases 503
    - nutrition. Imogene P. Earle 501–518
    - nutrition, summary 52–54
  - vitamin A requirements 24
  - vitamin deficiencies, effects 442–443
- Antibodies in blood and colostrum, functions 503, 504, 505
- Antimony, occurrence in human body 220
- Apricots, source of—
  - carotene 224–225
  - iron 201
- Arizona Agricultural Experiment Station, filtration of fluorine from water 213
- Arizona, forage crops, phosphorus deficiency 1031
- Arkansas, forage crops—
  - fluorine excess 1039
  - phosphorus deficiency 1031
- Arsenic, occurrence in—
  - foods 279
  - human body 217
- Ascorbic acid—
  - sources in foods 289
  - *See also* Vitamin C.
- Ash, mineral components, identification method and importance 213–214
- Atlantic coast region, swine production and feeding practices 728–729
- Australia, livestock disease caused by cobalt deficiency, and control 215–216

- Bacteria—
  - acetic acid, role in vinegar making 347–348
  - cause of organic decomposition 341–342
  - growth—
    - in eggs, detection methods 344–345
    - in meat, preventive methods 345–346
    - in milk, preventive methods 345
    - on vegetables, preventive measures 343
  - role in production of fermented foods 348–349
  - thermophilic growth on carbohydrates, prevention 346
- Bacterial—
  - action, function in digestion 429
  - infections, resistance of young animals 503
- Baldwin-Wood, normal heights and weights, boys and girls 5 to 18 years of age 165
- BALLS, A. K.: Enzymes in Foods and Food Preservation 350–354
- Barium, occurrence in human and animal tissues 219
- Barley, feeding to horses and mules 775
- Beef, source of iron in diet 202, 204
- Beer making, role of micro-organisms 347
- BENTLEY, F. L., statement on research in animal nutrition 1052–1053, 1054
- Beriberi—
  - cause, symptoms, and prevention 230–231, 233
  - result of vitamin deficiency 701
- Beryllium, excess in animals, result 219
- Bile, function in digestion 427, 429
- Bird—
  - feed stations, establishment, recommendations 909–910
  - feeding areas, size, location, and types of crops 909
  - shelters, establishment recommendations 909–910
- Birds, game, upland gallinaceous—
  - attitude toward new and poisonous foods 903–907
  - diet formulas 919
  - feeding practices 919–924
  - feeding requirements—
    - Ralph B. Nestler 893–924
    - summary 86–87
  - food selection and habits 900–907
  - food utilized, types 900
  - influence of age and season on food habits 903
  - mineral requirements 916–918
  - nutrition under controlled conditions 910–924
  - nutritional—
    - requirements 911–919
    - studies under natural conditions 900–910
  - physiology 897–900

Page

- Birds, game, upland gallinaceous—Continued.
  - propagation, extent 897
  - provisions for feed patches and shelters 907–909
  - range and description 894–897
  - various species, nutritional differences 898–900
  - vitamin requirements 914–916
- BIRDSEYE, MIRIAM: What the Modern Homemaker Needs to Know 372–379
- Bismuth, occurrence in human body 220
- Bitch, brood, feeding, recommendations 862–864
- BLACK, W. H.:
  - Nutritional Requirements of Beef and Dual-Purpose Cattle. With Bradford Knapp, Jr., and J. R. Douglas 519–543
  - Practices in the Feeding of Beef and Dual-Purpose Cattle 544–565
- Blindness, night, cause and control 24, 223, 226–227, 538–539
- Blood—
  - capillaries, fragility, test of vitamin C nutrition 239–240
  - constituents—
    - effects on milk secretion. C. A. Cary 694–698
    - relation to milk secretion. M. H. Friedman and C. A. Cary 685–698
    - relation to milk secretion, summary 67–68
  - copper and iron requirement 112–113
  - copper content 209
  - serum of—
    - dam, feeding as substitute for colostrum 505–506, 509
    - suckling animals, antibodies and globulins in 505
  - vitamin C content, test 239, 241–242
- Bobwhite. *See* Quail.
- Body—
  - building and repair, food requirements 103–104
  - weight—
    - averages, boys and girls 165–166
    - averages, men and women, according to height and age 161
    - control claims analysis 141–142
- Bone, calcium—
  - and phosphorus requirement 111, 117
  - requirements 187–188
- Bonemeal, function in diet of cows 534
- Bones—
  - calcium and phosphorus requirements 9
  - feeding to dogs, recommendations 862
  - formation, role of vitamin D 255–256
  - vitamin D requirement 117–118
- BOOHER, LELA E.:
  - Food Functions and the Relation of Food to Health. With Callie Mae Coons 100–123
  - Riboflavin 261–266
  - Vitamin A. With Elizabeth C. Callison 221–229
- Boron, functions in plants 218
- Boys—
  - calorie requirements in terms of age and body weight 164
  - energy allowances recording schedule 168
  - 5 to 18 years, Baldwin-Wood normal heights and weights 165
  - food energy, daily allowance suggestions 172
  - 1 to 60 months, height-weight averages 166
- Bran—
  - excess in diet of chickens, symptom 829
  - wheat, composition, and feed value 1021
- Bread—
  - making, role of yeast 348
  - whole-wheat, source of—
    - copper in diet 210
    - iron in diet 210
- Brewery byproducts—
  - composition and feed value 1021
  - feeding to swine 733–734
- Bromine, occurrence in human body 218
- Bulls—
  - dairy—
    - live weight and height, birth to 2 years 626
    - raising 623–624
  - wintering 548–549

Page

- **Burr, W. W.**, statement on research in animal nutrition 1051
- Butter—
  - grade labeling for consumers 369
  - value in diet as protective food 380–381
- Butterfat—
  - carotene and vitamin A concentrations, relation to carotene in feed 669
  - production, yearly, by breeds of cows having official records 642
  - vitamin A content 222, 224
- Buttermilk—
  - composition and total digestible nutrients 602
  - condensed, reconstituted, feeding to dairy calves 607–608
  - digestible nutrients and feed value per 100 pounds, comparison with fresh skim milk 602
  - dried, reconstituted, feeding to dairy calves 607–608
  - fresh, feeding to dairy calves 606–607
- Byproducts—
  - brewery—
    - and distillery, feeding to swine 733–734
    - composition and feed value 1021
  - farm—
    - digestible protein and digestible nutrient content for cattle, sheep, and swine, determinations 1074
    - percentage composition used in animal feeding 1071
  - utilization as livestock feeds 1017–1018

- Cabbage—
  - calcium content, analysis, technical notes 283
  - chemical composition, variations 281, 283
  - source of—
    - copper 210
    - iron 207
- Caesium, occurrence 219
- Calcium—
  - adult needs—
    - comparison with phosphorus requirements 194–197
    - estimate for individual and chance variations 190–191
    - minimal, for normal maintenance 189–190
    - optimal, for normal maintenance 191–192
  - assimilation—
    - by humans, function of vitamin D 193
    - in dairy cows, factors affecting 587
  - balance studies with children, results 193
  - content of—
    - cabbages, analysis, technical notes 283
    - foods, analysis, shortcomings 281–282
    - poultry feedstuffs 841
    - soybeans, analysis, technical notes 283
  - deficiency in forage crops, by States 1035
  - effect on hatchability of eggs 797
  - excess in chickens, effects and remedy 829
  - foods rich in, list 276–277
  - function in human body 9, 111–112
  - human requirements 18–19, 187–197
  - metabolism, role of vitamin D 255–256
  - needs of women during pregnancy and lactation 192
  - phosphorus intake, effect on chick embryonic mortality 799
  - requirements—
    - and source in feeds 533–538
    - for growing and fattening steers 537
    - for human growth and development 193–194
    - of chickens 814, 818
    - of dairy cattle 631–632
    - of dairy cows 585–586
    - of gallinaceous upland game birds 917–918
    - of horses and mules 770–772
    - of human nutrition. H. C. Sherman 187–197
    - of turkeys 814, 818
  - retention by children 193–194
- Calf meal—
  - composition 610
  - dry-fed, combined with limited quantities of milk, feeding to dairy calves 608–609
  - feeding—
    - directions 611–612
    - to dairy calves as milk substitute 609–612
- Calf meal—Continued.
  - reinforced, composition 611
- California, forage crops—
  - fluorine excess 1039
  - iodine deficiency 1036
  - phosphorus deficiency 1031
- **Callison, Elizabeth C.**: Vitamin A. With Lela E. Booher 221–229
- Calories—
  - human requirements 15–16
  - measurement of heat and energy 15–16
- Calves—
  - bull, raising 623–624
  - creep-fed, fattening 552–555
  - dairy—
    - effects of vitamin A deficiency in dams 633–637
    - feeding on—
      - calf meals, directions 611–612
      - fresh buttermilk or fresh whey 606–607
      - fresh skim milk after starting on whole milk 604–605
      - grain 613–615
      - grain as milk substitute 609
      - hay 613
      - limited quantities of milk with dry grain or dry-fed calf meal 608–609
      - mixtures containing percentages of protein 614
      - pasturage 615
      - reconstituted dried skim milk, dried buttermilk, or condensed buttermilk 607–608
      - silage 615
      - whole milk 605–606
    - milk, quantities for ration 603
    - 1 to 6 months, raising 598–615
    - raising on nurse cows 606
    - starting on whole milk 602–604
    - starting without whole milk 605
  - fattening ration in creep feeding 552–555
  - newborn, feeding methods 601–602
  - vitamin B complex requirement 542
  - water—
    - consumption, 3 to 24 weeks 637
    - requirement 637–638
  - weight, percentage of water 637
  - young—
    - care and management 598–601
    - feeding, recommendations 509–511
    - nutrition 501–511
- Cannibalism, occurrence and prevention in poultry 826
- Canning, foods—
  - effect on vitamin content 293–294
  - processing methods 344
- Carbohydrate—
  - abundant, with—
    - abundant nitrogen, effect on plants 413–414
    - deficient nitrogen, effect on plants 415
    - limited nitrogen supply, effect on plants 414–415
  - content of—
    - foods 275
    - milks 506–507
  - deficient, with abundant nitrogen, effect on plants 413
  - materials, spoilage prevention 346
  - reserve in plants, relation to fertilizers 411–412
- Carbohydrates—
  - digestible, classification 153–155
  - effect on—
    - heat production of animals 434–436
    - wool growth 499–500
  - function in—
    - diet 152–157
    - human body 110–111
  - human—
    - body requirements 13–14
    - food requirement. Helen S. Mitchell 152–157
  - indigestible, classification 155–156
  - metabolism—
    - function in body 156–157
    - interrelationship with other nutrients 157
  - relation to nitrogen supplies, four types 412–415
  - requirements of dogs 849

Page

Carbohydrates—Continued.
- sources of heat and energy, feeding to swine 729–732
- utilization by dogs 847–849

Carcass, dressed, proportion—
- of edible meat 462–464
- to total body weight 453–458

CARDON, P. V.:
- Pasture and Range in Livestock Feeding. With W. R. Chapline, T. E. Woodward, E. W. McComas, and C. R. Enlow 925–955
- The Nutritive Value of Harvested Forages. With T. E. Woodward, W. H. Hosterman, and E. W. McComas 956–994

Caries, dental, prevention in children 259

Carotene—
- content of cattle feeds 671
- in artificially dried hay 999
- properties and conversion into vitamin A 222, 224, 225
- quantity in feed, relation to concentrations of vitamin A and carotene in butterfat 669
- relation to green color of hay 966
- requirements of dairy cows 582
- source of vitamin A in milk 669–673
- value in diet of cows 539–541

Carotinoids, presence in foods 222, 224, 225

Carrots—
- source of carotene 225
- source of iron 201

CARY, C. A.:
- Blood Constituents 694–698
- Milk in Nutritional Research—A Sketch of Progress 699–705
- The Vitamins in Milk and in Milk Production 668–684
- Utilization of Feed Energy and Feed Protein in Milk Secretion 649–667
- Variations in the Composition of Milk. With P. A. Wright and E. F. Deysher 639–648

Casein, source 695

Cash expenditures for food—
- city and village families 303–308
- farm families 299–302

Cat—
- digestion in, description 424, 427
- mastication habits 422
- prehensive habits 419, 420

Cattle—
- beef—
  - and dual-purpose, feeding practices. W. H. Black 544–565
  - and dual-purpose, maintenance, proposed protein requirements 526
  - and dual-purpose, nutritional requirements. W. H. Black, Bradford Knapp, Jr., and J. R. Douglas 519–543
  - average daily rations 564–565
  - calcium and phosphorus requirement in feeds 533–538
  - energy requirements 519–525
  - fattening 552–562
  - feeding hay and concentrates to supplement pasturage 941–942
  - feeding practices, objectives 544–562
  - feeding practices, summary 56–57
  - function of minerals in body 529–530
  - growth and fattening, daily requirement of digestible nutrients 524
  - growth and fattening feed requirements 521–525
  - growth and fattening, protein requirement 526–528
  - maintenance, feed requirements 519–521
  - maintenance, protein requirement 525–526
  - maturity, relation to body composition 523–524
  - mineral deficiency, correction by supplementary feeding of minerals 531–533
  - mineral deficiency, symptoms 530–531
  - mineral requirements 529–538
  - nutritional requirements, summary 54–56
  - protein requirements 525–528
  - reproduction, protein requirements 528
  - summer grazing 550–552
  - vitamin requirements 538–543
  - wintering 545–550

Page

Cattle—Continued.
- breeding herds, wintering 545–548
- dairy—
  - calcium and phosphorus requirements 632
  - copper requirements 632
  - feeding essentials 591
  - feeding hay and concentrates to supplement pasturage 939–941
  - growth, feed requirements 626–638
  - growth rates 624–626
  - maintenance, energy requirements 655
  - mineral requirements 631–632
  - nutritional requirements 624–638
  - protein requirements 628–631
  - total digestible nutrient requirements 626–628
  - vitamin requirements 633–637
  - young, practical feeding and nutritional requirements, summary 60–63
  - *See also* Cows, dairy.
- dual-purpose—
  - and beef, nutritional requirements. W. H. Black, Bradford Knapp, Jr., and J. R. Douglas 519–543
  - average daily rations 564–565
  - feeding practices, objectives 562–563
  - feeding practices, summary 56–57
  - nutritional requirements, summary 54–56
- feed-unit requirements per 100 pounds of gain in dry-lot feeding 558
- feeds, carotene content 671
- fetus, daily protein requirement 528
- maintenance, daily requirement of total digestible nutrients 520
- night blindness, result of vitamin A deficiency 538–541
- nutrition, beef and dual-purpose, summary 54–56
- production, economic necessity for nutritional information 519
- vitamin A deficiency, symptoms 538–541

Cauliflower, source of—
- copper in diet 210
- iron in diet 204

CAVIN, J. P.: Agricultural Programs and the Nutritional Goal 396–402

Cellulose—
- function in diet 155
- source of heat and energy 435–436

Cereals—
- byproducts, protein content and feed value 1020–1022
- feeding to dogs, recommendations 860–861
- source of copper 210
- source of iron 201, 202, 203, 278
- source of phosphorus 277

Cerium, occurrence in human body 220

Cevitamic acid, commercial form of vitamin C 236

CHAPLINE, W. R.: Pasture and Range in Livestock Feeding. With P. V. Cardon, T. E. Woodward, E. W. McComas, and C. R. Enlow 925–955

CHATFIELD, CHARLOTTE: Food Composition. With Georgian Adams 272–285

Chewing in domestic animals, comparison 422–423

Chicken—
- conditioners, use, disadvantages 826
- embryo, content, effect of diet 792
- feeds, mixing ingredients, recommendations 832–833
- source of copper 210

Chickens—
- anti-gizzard-erosion factor in feed, occurrence 825
- breeding stock—
  - diets for, recommendations 834
  - mashes for, recommendations 835–836
- diarrhea, causes 829
- diet—
  - balancing, advantages 789
  - effect on composition and value of eggs 806–807
  - effect on composition of egg and embryo 791–793
  - effect on hatchability of eggs 790–791, 793–798
  - requirements for egg production 804–806
  - supplying nutritive elements 820–826
- dietary excesses, results 829
- diseases, causes and symptoms 827–829
- egg eating, causes 827

Chickens—Continued. Page

- embryonic mortality, time of occurrence 799
- feed—
  - cost, relation to efficiency of egg production 802–803
  - formulas, typical, preparation 832–837
- feeding—
  - all-mash system, description and advantages 830
  - grain-milk system, description and advantages 832
  - mash-grain system, description and advantages 830–832
  - mashes with grain, recommendations 834
  - pellet system, description and advantages 832
  - practical 80, 819–836, 837–843
- feedstuffs, digestibility 842
- gizzard erosion, types 829
- growing, diets for, recommendations 833–834
- growth, nutritive requirements 809–817, 818
- laying—
  - diets for, recommendations 834
  - mashes for, recommendations 835–836, 837
- males, diet, effects 790
- nutrition, relation to egg production 799–807
- nutritive requirements 77–79, 787
- reproduction—
  - comparison with that of other farm animals 789
  - effect of nutrition 789–799
- utilization of feed for growth, comparison with other breeds of poultry 810–811

Chicks—

- antidermatosis factor—
  - deficiency, symptoms 829
  - in feed, occurrence 825
- dermatosis, remedies 268–269
- growing, mashes for, recommendations 835

Children—

- anemia, occurrence and control 201–203, 209
- calcium—
  - balance studies 193
  - retention 193–194
- calorie requirements in terms of age and body weight 164
- copper requirements 210
- energy output 164–166
- iron requirements 202–204
- 1 to 3 years, food energy, daily allowance suggestions 172
- 1 to 5 years, relative energy allowances, recording schedule 168
- 1 to 12 years, proportion of adult basic requirement and basic number of calories per day 167
- phosphorus requirements 195–196
- vitamin B_1 requirements 234
- vitamin C—
  - daily allowance 255
  - requirements 246–247
- vitamin D—
  - daily allowance 259
  - requirements 257–259

Chlorine—

- occurrence in foods 279
- requirements of gallinaceous upland game birds 916–917

Chlorophyll, relation to green color of hay 966

CHRISTENSEN, F. W., statement on research in animal nutrition 1049

Chromium, occurrence in human body 220

Citrus fruit, value in diet as protective food 380–381

CLARK, FAITH: Planning for Good Nutrition. With Hazel K. Stiebeling 321–340

Climate, effect on—

- nutritive value of forage crops 961–962
- vitamin content of plant foods 291–292

Cobalt—

- deficiency in—
  - forage crops, by States 1038–1039
  - in livestock, causes and remedy 215–216
- occurrence in—
  - foods 279
  - human body, and benefits 216
- requirement of dairy cattle 632

Page

Cocarboxylase, formation and function in human body 232

Coconut oil byproducts, protein content and feed value 1020

Cod-liver oil—

- requirements for vitamin D potency 258, 259
- source of vitamin D 29

Coenzymes, function in body 269

Colorado, forage crops—

- cyanide excess 1041
- iodine deficiency 1036

Coloring—

- green, association with vitamin A 222, 224, 225
- yellow, association with vitamin A 222, 224, 225

Colostrum—

- composition—
  - and total digestible nutrients 602
  - functions, and substitutes for 503–506
- value to newborn calf 603
- vitamin content 505
- vitamin A potency 672
- vitamin B_1 content, comparison to vitamin B_1 in later milk 677

Colt—

- production, nutrient requirements for mare 784–785
- *See also* Foal.

Columbia University, work in calcium nutrition 189–190, 193

Concentrates—

- feeding to—
  - dairy cows, importance and methods 568–570
  - horses and mules 774–778
- mill—
  - digestible protein and digestible nutrient content for cattle, sheep, and swine, determinations 1071–1072
  - percentage composition used in animal feeding 1067–1068
- use as supplement for pasturage in livestock feeding 939–942

Conference on Energy Metabolism, definition of terms used in studies 435

Consumer—

- and food grades. Marius Farioletti 364–372
- eating habits, need for educational program 401
- labels, use in food quality identification 371
- low-income level, income-increase possibilities 390–391
- use of grade standards 366–368

CONVERSE, H. T.: Practical Feeding and Nutritional Requirements of Young Dairy Stock. With Joseph B. Shepherd 597–638

Cooking, foodstuffs, effect on vitamin content 294–295

COONS, CALLIE MAE:

- Food Functions and the Relation of Food to Health. With Lela E. Booher 100–123
- Present-Day Diets in the United States. With Hazel K. Stiebeling 296–320

Copper—

- association with iron in foods 208–209
- content in milk 646–647
- function in human body 9, 113, 209–210
- human requirements—
  - Mabel A. Dickson 197–211
  - summary 21
- needs of women during pregnancy and lactation 211
- occurrence in foods 278–279
- requirement of dairy cattle 632
- sources in foods 208–209

Corn—

- byproducts, composition and feed value 1021
- feeding to horses and mules 774–775
- oil meal, protein content and feed value 1019
- stover, feed value 1023
- yellow, source of vitamin A 224, 225

Corn Belt, swine production and feeding practices 725–727

Cornell Animal Nutrition Laboratory, experiments with minks 889

Cornell University, researches with minks, results 886–889

Page

- Corpus luteum, extract, action on mammary glands ... 686–687
- Cottonseed—
  - byproducts, protein content and feed value ... 1018–1019, 1020
  - meal—
    - effect on color of eggs ... 807
    - feeding to horses and mules ... 775–776
- Cows—
  - age at first calving, relation to butterfat production and estimated mature live weight ... 622
  - butterfat production, relation to age at first calving ... 622
  - carotene requirement in diet ... 539–541
  - dairy—
    - calcium and phosphorus assimilation, factors affecting ... 587
    - calcium requirements ... 585–586
    - carotene requirements ... 582
    - daily food requirements for maintenance and milk production ... 571
    - dietary deficiencies, discussion ... 587–589
    - energy requirements ... 575–578
    - fat requirements ... 580–581
    - feeding and care, procedure ... 571–575
    - feeding for intensive milk production, practices, summary ... 57–59
    - feeding for intensive milk production in practice. Edward B. Meigs ... 566–591
    - feeding grain mixtures ... 592–593
    - feeding iodine concentrate ... 212
    - feeding roughages and concentrates, methods and importance ... 568–570
    - health, chemical compounds necessary ... 578–587
    - iodine requirements ... 587
    - milk composition, variations ... 62–63
    - nutritional experiments, problems ... 566–568
    - pathological conditions due to dietary deficiencies ... 590
    - phosphorus requirements ... 586–587
    - protein requirements ... 579–580
    - rations, allocation, summary ... 59–60
    - rations, figuring. T. E. Woodward ... 592–596
    - replacement problem ... 597
    - summer feeding ... 594–595
    - vitamin A requirements ... 581–585
    - winter feeding ... 595–596
    - *See also* Cattle, dairy.
  - energy feeding standards, relation to experimental data ... 654–656
  - 5 breeds, milk composition ... 641
  - lactation period, phases, influence on milk composition ... 645
  - mature live weight, effect of first-calving age ... 622
  - milk—
    - and butterfat production, annual, by breeds having official records ... 642
    - secretion, utilization of feed energy and feed protein ... 649–667
  - nurse, value in raising calves ... 606
  - value of bonemeal in diet ... 534
- Cozymase, constituents, function and presence in blood ... 269
- Cream, market, State and municipal requirements ... 360
- Crema method of making silage, description ... 1011
- Crops, fresh, feed value ... 1015–1016
  - green—
    - acids, bases, and dry matter in, comparison ... 1014
    - ensiling, composition before and after ... 1015
- Cryptoxanthin, occurrence in foods, and conversion into vitamin A ... 222, 224
- Cyanides, excess in forage crops in Colorado ... 1041
- Cystine, requirements for wool production ... 498–499

- Dairy—
  - cows. *See* Cows, dairy.
  - products—
    - source of calcium ... 276
    - source of phosphorus ... 277
    - source of riboflavin ... 264
    - vitamin A and carotene content ... 222, 224
  - stock—
    - feeding practices ... 598–624

Page

- Dairy—Continued.
  - stock—Continued.
    - young, practical feeding and nutritional requirements. Joseph B. Shepherd and H. T. Converse ... 597–638
- DANIEL, ESTHER PETERSON:
  - Trace Elements ... 213–220
  - Vitamin Content of Foods ... 286–295
- Defu solution, use in making silage ... 1010–1011
- Dental caries, relation to diet ... 121–122
- Dextrins, function in diet ... 155
- DEYSHER, E. F.: Variations in the Composition of Milk. With P. A. Wright and C. A. Cary ... 639–648
- Diarrhea in chickens, causes ... 829
- DICKSON, MABEL A.: Iron and Copper Requirements ... 197–211
- Diet—
  - carbohydrate content ... 152
  - chicken's, effect on composition and value of eggs ... 806–807
  - formulas, for gallinaceous upland game birds ... 919
  - quality, relation to family purchasing power ... 382–384
  - relation to—
    - dental caries ... 121–122
    - disease resistance ... 122–123
    - function of pituitary gland ... 693–694
    - reproduction. Ralph W. Phillips, M. H. Friedman, and W. A. Turner ... 476–491
    - reproduction, summary ... 50–52
  - tables, appendix ... 337–340
  - value of fats ... 157–158
- Dietary—
  - diseases, effect of vitamin deficiencies ... 701–705
  - habits—
    - building up, problem ... 11
    - national, changes ... 129–130
    - trends ... 126–130
  - ingredients, unidentified, effect on reproduction ... 490
  - panaceas, for disease prevention, misleading claims ... 143–144
  - standards, present and improved, relation to food production requirements ... 398–400
- Diets—
  - adequate, relation to food selection ... 384–385
  - carbohydrate requirements ... 13–14
  - contributions by different groups of foods ... 326–327
  - deficient—
    - and resultant diseases ... 104–105
    - effect on feed utilization and health of farm animals ... 438–443
    - in vitamins, relation to animal fertility ... 485–487
    - relation to pathological conditions in dairy cows ... 590
  - differences among peoples ... 10–11
  - economical fair, description ... 333, 334–336, 337
  - expensive, good, description ... 333–336, 339
  - fat requirements ... 14–15
  - four—
    - proposed, money value and recommendations ... 334–336
    - recommendations by Bureau of Home Economics ... 35–36
  - good—
    - and fair, daily allowances of nutrients ... 310, 320
    - quantities of foods per person per year ... 312
  - improvement, recommendations ... 314–315
  - low-cost good, description ... 332, 334–336, 338
  - mineral requirements for reproduction ... 487–488
  - moderate-cost good, description ... 332, 334–336, 339
  - nutritive value—
    - and adequacy ... 308–312
    - factors affecting ... 329–332
  - of city and village families ... 302–308
  - of farm families, studies ... 297–302
  - present-day—
    - in United States. Hazel K. Stiebeling and Callie Mae Coons ... 296–320
    - in United States, statistics ... 316–320
    - in United States, summary ... 33–34
  - protective foods in average quantities ... 327–329
  - protein-deficient, quantitative or qualitative effect on farm animals ... 438–440

Diets—Continued. Page
purchasable for sums generally allotted to food by families of differing size and income 382
United States 316–320
village and urban, caloric percentage in food-group trends 128
Digestion, in domestic animals—
comparison 424–429
summary 45–47
Digestive—
processes, in domestic animals. H. W. Schoening 418–430
tract, description and function 418–419
Dinner, Christmas, 1680 and 1939, menus 40, 373–375
Diphtheria, control by use of vitamin C 253–254
Diseases—
deficiency, relation to lack of vitamins 701–705
dietary-deficient, contributing factors 104–105
human—
control by use of vitamin C 235–236, 238–239, 250–254
vitamin C requirements 250–254
infectious, immunity of—
infant 503
young animals 503
mineral-deficient, survey 535–538
resistance to, effect of diet 122–123
Distillery byproducts, feeding to swine 733–734
Dog foods, canned, contents and value 861–862
Dogs—
blacktongue—
cause and prevention 30, 855
remedies 268
similarity to pellagra 267
carbohydrate utilization 845, 847–849
digestion—
description 424, 427
physiology 846–847
diseases due to vitamin deficiency 854–855
energy requirements 852–853
feed—
deficiencies 868
description and value 856–862
economies, recommendations 867–868
quantities required, recommendations 866–867
feeding—
S. R. Speelman 856–870
bones, recommendations 862
cereals and cereal products, recommendations 860–861
meats and fish 856–859
opinions 845–846
practices, recommendations 862–864
suggestions in brief 868
summary 82–84
vegetables, recommendations 859
mastication habits 422
mineral requirements 853–854
nutritional requirements—
Imogene P. Earle 844–855
summary 81–82
prehensive habits 419, 420
proportions of carbohydrate and fat in diet 849
protein requirements 845, 849–852
rickets, causes and remedies 853–854, 855
stud, feeding, recommendations 864
vitamin requirements 854–855
water supply, recommendations 862
DOUGLAS, J. R.: Nutritional Requirements of Beef and Dual-Purpose Cattle. With W. H. Black and Bradford Knapp, Jr 519–543
Drugs, transmission to cow's milk 648
Drying, foods, effect on vitamin content 293
Ducks, utilization of feed for growth, comparison with other breeds of poultry 810–811
DUTCHER, R. A., statement on research in animal nutrition 1054

EARLE, IMOGENE P.:
Nutritional Requirements of Dogs 844–855
The Nutrition of Very Young Animals 501–518
The Relation of Nutrition to the Production of Hides and Wool. With John I. Hardy 492–500
Eating habits, relation to food-consumption programs 401

Page
Egg—
characteristics 799–800
composition 800
composition, effect of hen's diet 791–793
formation, physiological process 800–801
production—
dietary requirements 804–806
diets for, recommendations 834
efficiency, relation to feed cost 802–803
mineral requirements 805–806
nutritive requirements 801–802
protein requirements 804–805
relation to nutrition of chicken 799–807
vitamin requirements 806
yolk—
color, factors affecting 806–807
vitamin A content 222, 224
"Egg-makers," use, disadvantages 826
Eggs—
composition and value, effect of chicken's diet 806–807
freezing, processing methods 345
grade labeling for consumers 369
hatchability, effect of—
calcium intake by hens and by pullets 799
carbohydrate content of diet 794–795
hen's diet 790–791
minerals in diet 797–798
protein content of diet 793–794
vitamin content of diet 791, 795–797
source of—
copper 210
iron 201, 202, 203
riboflavin in diet 264
soilage, effect of diet 807
spoilage prevention 344–345
storage changes 354
value in diet as protective food 380–381
Eggshells, quality, factors affecting 807
Elements—
nutritive, sources and cycles—
E. J. Kraus 405–417
summary 44–45
trace. *See* Trace elements.
ELLIS, N. R.:
Composition of the Principal Feedstuffs Used for Livestock. With W. R. Kauffman and C. O. Miller 1065–1074
Nutritive Requirements of Swine. With J. H. Zeller 706–722
Practices in Swine Feeding. With J. H. Zeller 723–745
Employment, relation to income distribution 388–389
Endocrine glands, factors affecting milk secretion. M. H. Friedman 685–694
Energy—
allowances, relative, recording schedule 168
derivation from—
fats 14–15
food 101–103, 156, 157
vitamin B 232, 234–235
feed—
and feeding standards 649–656
utilization in milk secretion. C. A. Cary 649–667
utilization in milk secretion, summary 63–64
human requirements. Nancy B. Morey 160–172
in poultry, nutrients producing 820–821
measurement by calories in diet 15–16
metabolism—
function of riboflavin 265
of farm animals, relation to heat-producing values of food constituents 434–436
output per kilogram of body weight per hour for different activities 163
production—
relation to inadequate food intake and protein utilization 440–441
relationship to food consumed 521
requirements—
determination 162
for wool production 498–499
of animals 436–438
of beef cattle 519–525
of dairy cows 575–578

Energy—Continued. Page
requirements—continued.
of horses and mules 767–769
of swine 710–714, 729–732
standards, establishment 166–169
variation 162–166
storage by plants 406–407
utilization in milk secretion, experiments 650–656
Enlow, C. R.: Pasture and Range in Livestock Feeding. With P. V. Cardon, W. R. Chapline, T. E. Woodward, and E. W. McComas 925–955
Enterokinase, function in digestion 429
Enzymes—
digestive, origin and action 427–429
in foods—
and food preservation. A. K. Balls 350–354
summary 37–38
Erepsin, function in digestion 429
Estrin—
action on mammary glands 686–687
effect of milk secretion 688–689
Ewes—
feeding for—
hothouse lamb production 751
increased yields 752–753
"flushing," for increased yields 752
pregnant, ration requirements 753
See also Lambs; Sheep.
Excretion, relation to weight of animals 437
Exercise, effects on meat animals 474–475
Eyes—
disease caused by deficiency of vitamin A 221–222, 223–224
proper functioning, relation to vitamin A 3–4
vitamin A requirement 115
Eyesight, improvement by liver in diet, knowledge of ancients 221

Families—
city, diets, studies 302–308
different levels, food expenditures, studies 322–323
differing size and income, diets purchasable for sums generally allotted to food 382
low-income, availability and distribution of food surpluses to 394–396
village, diets, studies 302–308
Family—
purchasing power, relation to quality of diet 382–384
workingman's, annual purchases of 58 foods, estimated retail value and equivalent farm value 393
Farioletti, Marius:
Food Grades and the Consumer 364–372
The Problem of Income and Its Distribution 385–392
Farm—
families, diets, studies 297–302
feeds, substitution in rations for dairy cows, suggestions 589
home, value as food-processing unit 379
surpluses, relation to adequate diet 391–392
Fat—
content, of—
lean meat, significance 461–462
milks 506–507
distribution, significance in meat 460–462
in hen's diet, relation to hatchability of eggs 794–795
in milk, source 697–698
relation to other diet constituents 159–160
requirements of dairy cows 580–581
Fats—
content of foods 275
contributions to diet 327
effects on—
heat production of animals 434–436
reproduction 488–490
function in human body 109–110, 158–160
human food requirement. Jane G. Lease 157–160
requirements of—
dogs 849
humans 8
livestock, limited knowledge 1056–1057
sources of heat and energy, feeding to swine 729–732
Fats—Continued. Page
value in diet 157–158
Fattening, definition, comparison with growth 526
Fatty acids, in milk, source 697
Feed—
constituents, in hay, losses in field curing 996
energy—
and feeding standards 649–656
in milk secretion, utilization. C. A. Cary 668–684
flavors and odors, transmission to cow's milk 648
protein—
in milk secretion, utilization. C. A. Cary 668–684
sources, biological value in milk production 666
utilization—
by farm animals, factors affecting. Louis L. Madsen 431–449
by farm animals, factors affecting, summary 47–48
by poultry for growth 807–811
for growth, measuring the efficiency 465–467
of byproducts 1017–1018
Feeding—
areas, for game birds, size, location, and feed 909
practical—
methods for dairy stock 598–624
young dairy stock, summary 60–63
practices—
beef and dual-purpose cattle. W. H. Black 544–565
beef and dual-purpose cattle, summary 56–57
for swine. J. R. Zeller and N. R. Ellis 723–745
regimes, relation to types and kinds of animals, suggestions for research 1059–1064
requirements, gallinaceous upland game birds, feeding practices 893–924
standards, and feed energy 649–656
See also Nutrition; *also* under specific class of livestock.
Feeds—
calcium and phosphorus requirement 533–538
energy and protein utilization through milk secretion. C. A. Cary 649–667
farm, substitution in rations for dairy cows, suggestions 589
for dairy cows, amounts required, determination 570–571
for horses and mules—
kinds 773–780
preparation 778–779
for swine, sources of energy and fat 729–732
mineral—
content 531–533
content, percentage in substance fed 532
miscellaneous, nutritive value—
Earl W. McComas and Thompson E. Woodward 1017–1026
summary 93–94
protein levels, experiments 662–667
relation to specific types and kinds of animals, suggestions for research 1059–1064
unit requirement in production of 100 pounds of gain in cattle fed in dry lot 558
values, general problems 1063–1064
Feedstuffs—
digestible protein and digestible nutrient content for cattle, sheep, and swine, determinations 1071–1074
percentage composition used in animal feeding 1067–1071
principal, used for livestock, composition. N. R. Ellis, W. R. Kauffman, and C. O. Miller 1065–1074
supplementary, utilization 1025–1026
Fertilizers—
effects on—
nutritional value of pastures 936–938
pastures, research 952–955
iodine, use 212
relation to carbohydrate reserve in plants 411–412
Fetus, animal, developing, nourishment 503
Fish—
feeding to dogs, recommendations 856–859

- Fish—Continued. Page
  - liver oils, vitamin A content 222, 224
  - meal, protein content and feed value 1024
  - oils, vitamin content and feed value 1025–1026
  - source of—
    - copper 210
    - iron 204
- Fishers, characteristics and studies 890–891
- Florida, forage crops—
  - calcium deficiency 1035
  - cobalt deficiency 1038
  - copper deficiency 1037
  - phosphorus deficiency 1031
- Fluorine—
  - and iodine. Margaret Cammack Smith 211–213
  - body requirements 21–22
  - excess in forage crops, by States 1039
  - sprays, use, control for prevention of fluorosis 213
  - tolerance of body for 212–213
- Fluorosis of teeth, cause, extent, and control 212–213
- Foals, young—
  - feeding, recommendations 511–512
  - nutrition 501–509, 511–512
- Food—
  - absorption, by domestic animals, description 429–430
  - advertising—
    - ethical and unethical methods 140
    - misleading, attacks on 144
  - alkalizing, misleading advertising 142
  - and life, summary. Gove Hambidge 3–94
  - chemical composition, data, use for calculations 272–274
  - choice, psychological factors 135–137
  - city and village family—
    - supply, relation to income 317
    - trends in food consumption, 1885–1937 313
  - combination fads, uselessness 143
  - composition—
    - Charlotte Chatfield and Georgian Adams 272–285
    - summary 30–32
    - tables, items contained 274–275
  - constituents—
    - for body building and repair 103–104
    - relative heat-producing values 434–436
  - consumption—
    - city families 318–319
    - factors affecting 400–401
    - fifty-year trends 312–314
    - relationship to energy production 521
    - requirements, as determinant of agricultural adjustment objectives 397–398
    - subsidizing. F. V. Waugh 392–396
  - distribution costs, relation of price to supply 401
  - energy—
    - daily allowance suggestions 172
    - standards, development, history 169–172
  - expenditures—
    - amounts required in good diets 382 383
    - by families 322–323
    - city families, 1935–36 304, 318
    - village families, 1935–36 303
  - fads, facts, and fancies—
    - Helen S. Mitchell 139–144
    - summary 11–12
  - functions—
    - and relation to health. Lela E. Booher and Callie Mae Coons 100–123
    - relation to health, summary 7–10
  - grades—
    - and consumer. Marius Farioletti 364–372
    - use by consumer, summary 39
  - groups—
    - caloric percentage in village and urban dietary trends 128
    - contributions to diet 326–327
  - habits—
    - changes, discussion 11
    - evolution 124–126
    - good, problems in teaching 137–138
    - in domestic animals, comparison 419–421
    - old and new. Hazel K. Stiebeling 124–130
- Food—Continued. Page
  - habits—continued.
    - old and new, summary 10–11
    - possibility of change. Paul E. Howe 131–138
    - relation to longevity 120–121
    - trends, significance 128–129
  - iodine content, increase, recommendations 212
  - legends and notions, origin 144
  - material—
    - dead, storage methods 353–355
    - live, storage methods 351–353
  - micro-organisms in, and food preservation. Harry E. Goresline 341–349
  - preservation—
    - and enzymes in foods. A. K. Balls 350–354
    - and micro-organisms in food. Harry E. Goresline 341–349
    - relation of enzymes to, summary 37–38
    - relation to micro-organisms, summary 36–37
  - production—
    - for farm family use, value and cash savings 297–301, 316
    - requirements, under present and improved dietary standards 398–400
  - quacks, warning against 139–140
  - relation to—
    - health, and functions. Lela E. Booher and Callie Mae Coons 100–123
    - human physical development 97–99
  - requirements, human—
    - of carbohydrates, fats, and energy. Helen S. Mitchell, Jane G. Lease, and Nancy B. Morey 152–172
    - summary 13–30
  - sales in retail markets, 1920–37 314
  - selection, relation to dietary adequacy 384–385
  - source of energy 101–103
  - spoilage, relation to presence of micro-organisms 36–37
  - stamp plan, value in food surplus distribution to low-income families 396
  - supplies, regional differences 301–302, 306–308, 336
  - utilization, relation to—
    - phosphorus deficiency 441–442
    - vitamin deficiencies 442–443
- Foods—
  - calcium content, analysis, shortcomings 281–282
  - canned, application of brand names 368
  - canning—
    - effect on vitamin content 293
    - for spoilage prevention 344
  - carbohydrate content 275
  - chemical—
    - composition, variability 273
    - elements, identification by spectrograph 214
  - commercially processed, effect on homemaking skills 375–377
  - cooking, effect on vitamin content 294–295
  - decay, causes 350–351
  - effective in prevention and cure of pellagra 269–270
  - energy-producing, relation of inadequate intake to protein utilization 440–441
  - fat content 275
  - fermented, utilization of bacteria 348–349
  - for control of weight, types 12
  - freezing—
    - effect on vitamin content 293
    - for spoilage prevention 343–344
  - frozen, prevention against spoilage 37
  - grade standards—
    - commercial value 364–366
    - consumer value 366–368
  - health, fallacy 11–12
  - home production and farm processing, effect on household economy 377–379
  - iron content, analysis—
    - shortcomings 282
    - technical notes 285
  - manufacture and preservation by micro-organisms 37
  - marketing and production methods, need for more efficiency 392–394
  - micro-organisms in, and food preservation—
    - Harry E. Goresline 341–349
    - summary 36–37

Page

- Foods—Continued.
  - mineral—
    - analyses, technical notes 283
    - analysis, shortcomings 280-282
    - content 275-285
  - moisture content 274
  - nutrients in, economical sources 323-327
  - oversupplying to farm animals, results 443-446
  - phosphorus content, analysis, shortcomings 282
  - preservation—
    - and processing, use of micro-organisms 346-349
    - effect on vitamin content 292-293
  - production and marketing methods, need for more efficiency 392-394
  - protection and storage 342-346
  - protective—
    - kinds and value in diet 380-382
    - studies 327-329
  - protein content 274-275
  - quality identification, consumer-label systems 371
  - riboflavin content, quantitative determination 264-265
  - rich in—
    - copper 208, 210
    - iron 201-202, 203-204, 207-208
  - source of—
    - calcium 276-277
    - essential nutrients 132-134
    - iron 277-278
    - phosphorus 277
  - spoilage, relation to presence of enzymes 37-38
  - standardization, purpose 364
  - storage, relation to vitamin content 292-293
  - surplus—
    - availability to low-income families 395-396
    - free distribution by kinds 394-395
    - utilization 394-396
  - vitamin content—
    - Esther Peterson Daniel 286-295
    - determination 286-287
    - discovery 68-69
    - factors affecting 291-295
    - suggestion for conserving 295
    - summary 32-33
  - vitamin A—
    - distribution 224-225
    - measurement, quantitative 225-226
- Forage—
  - composition 1014-1015
  - crops—
    - growth, effect on nutritive value 958-959
    - leaves versus stems, relative nutritive values 959-961
    - leguminous, nutritive values 962-964
    - nonleguminous, nutritive values 962-964
    - soiling, effect on nutritive value 970
    - yields, reduction by insect pests and diseases 965
  - grasses and legumes in grazing regions 927-928
  - mineral deficiency and excess. A. M. Hartman 1027-1044
  - nutritive value, factors affecting 958-965
  - problems, suggestions for research 1059-1060
  - production on ranges—
    - maintenance, relation to livestock production 948-951
    - types and species 946-951
  - selenium content, effects on livestock 1040-1041
  - yields, correlation with animal yields 954-955
- Forages—
  - dried—
    - digestible protein and digestible nutrient content for cattle, sheep, and swine, determinations 1073
    - percentage composition used in animal feeding 1070-1071
  - green, digestible protein and digestible nutrient content for cattle, sheep, and swine, determinations 1073
  - green, percentage composition used in animal feeding 1069
  - harvested, nutritive value—
    - T. E. Woodward, W. H. Hosterman, P. V. Cardon, and E. W. McComas 956-991
    - summary 89-91

Page

- FORBES, E. B., statement on research in animal nutrition 1049
- Fowl—
  - digestion in, description 425
  - prehensive habits 420-421
  - *See also* Poultry; *also* under specific kinds.
- Foxes—
  - diseases due to vitamin B deficiency 879
  - livers, vitamin A content, comparative data 878
  - silver—
    - characteristics and breeding habits 872-873
    - feed costs, reduction 876
    - feeding during reproductive period, recommendations 884-885
    - feeding from breeding time through lactation, experiments 882, 883
    - feeding, recommendations 883-885
    - feeds and feeding practices 874-876
    - management practices 873-876
    - mature, summer and fall maintenance, experiments 880-881
    - mature, summer and fall maintenance, recommendations 883-884
    - nutritive requirements 876-879
    - pups, summer and fall feeding, recommendations 885
    - vitamin A requirements and storage 877-879
    - vitamin B requirements 879
    - weaned pups, summer and fall feeding, experiments 881-882
- Freezing—
  - eggs, processing methods 345
  - foods, effect on vitamin content 293
  - foods, processing methods 343-344
- FRIEDMAN, M. H.—
  - Endocrine Factors 685-694
  - Glands, Hormones, and Blood Constituents—Their Relation to Milk Secretion 685-698
  - Nutrition and Reproduction. With W. A. Turner 482-491
  - The White Rat as Contributor to Science 145-151
- Fruits—
  - contributions to diet 326, 327
  - decay by yeasts and molds 36-37
  - grade—
    - labeling problems 369
    - standards for 367
  - heat production per ton per day at several temperature levels 352
  - juices, protection from yeasts and molds 342-343
  - protection from yeasts and molds 342
  - source of—
    - calcium 276
    - carotene in diet 224-225
    - copper 210
    - iron 201, 203, 208, 278
    - riboflavin 264
  - storage changes 351-353
  - sulfuring, effect on vitamin B_1 232
- FUNCHESS, M. I., statement on research in animal nutrition 1051
- Fur animals, nutrition—
  - Charles E. Kellogg 871-892
  - summary 84-86
  - research 872, 879-880

- Game birds. *See* Birds, game.
- Gastric juice, function in digestion 427
- Germanium, occurrence and function in blood 220
- Gingivitis, cause and cure 251-252
- Girls—
  - caloric requirements in terms of age and body weight 164
  - 5 to 18 years, Baldwin-Wood normal heights and weights 165
  - food energy, daily allowance suggestions 172
  - 1 to 60 months, height-weight averages 166
  - relative energy allowances, recording schedule 168
- Glands, relation to milk secretion—
  - M. H. Friedman and C. A. Cary 685-698
  - summary 66-67
- Globulins in colostrum and blood serums, functions 504, 505

Page

- Glucose, conversion into milk sugar 694-695
- Glycogen, function in diet 154-155
- Goats—
  - Angora, feeding requirements 758, 760
  - feeding—
    - for meat production 762
    - problems. Damon A. Spencer 758-762
    - problems, summary 74-75
  - milk—
    - feeding practices 758, 760-761
    - improvement through nutritional research 762
  - *See also* Kids.
- Goiter—
  - belt, extent 212
  - cause and prevention 212
- Goresline, Harry E.: Micro-organisms in Foods and Food Preservation 341-349
- Gortner, R. A., statement on research in animal nutrition 1054, 1056, 1057
- Grain—
  - amounts needed for each pound of milk produced, and digestible nutrients 393
  - dry, combined with limited quantities of milk, feeding to dairy calves 608-609
  - feed requirement in normal growth of heifers up to 2 years 599
  - feeding to dairy calves 609, 613-615
  - mixtures—
    - containing percentages of protein, for young dairy stock 614
    - feeding to dairy cows 592-593
    - protein content to be fed with different roughages 593
  - storage changes 353
- Grains—
  - digestible protein and digestible nutrient content for cattle, sheep, and swine, determinations 1071-1072
  - milling, effect on vitamin B_1 content 232
  - miscellaneous, feeding to horses and mules 775
  - percentage composition used in animal feeding 1067-1068
- Grass—
  - dried, composition and digestibility on water-free basis 1001
  - dry, nitrogen content 996
  - field, composition, digestibility, and digestible nutrients 994
  - fresh, composition and digestibility on water-free basis 1001
  - freshly cut, digestibility coefficient 1000
  - kiln-dried, digestibility coefficient 1000
  - pasture, fresh and dried, chemical composition 999
  - young, artificially dried, feed value 1000-1001
- Grasses—
  - comprising forage in grazing regions 927-928
  - nutritional value, effect of rainfall 935
- Grazing—
  - methods—
    - farm pastures 932-935
    - livestock 932-935
  - practices, effect on nutritional value of pastures 938-939
  - regions—
    - grasses and legumes comprising forage 927-928
    - major, in United States 926
  - species, selection for nutritional values 935-936
- Green—
  - coloring, association with vitamin A 222, 224, 225
  - forages—
    - digestible protein and digestible nutrient content for cattle, sheep, and swine, determinations 1073
    - percentage composition used in animal feeding 1069
- Grit—
  - function in chicken feed, recommendations 826
  - requirements of gallinaceous upland game birds 918
- Grouse—
  - feeding requirements 900-903, 910
  - range and description 894-895
- Growth, definition, comparison with fattening 526
- Gums, bleeding, cause and cure 251-252

Page

- Ham souring, cause 345-346
- Hambidge, Gove: Food and Life—A Summary 3-94
- Hankins, O. G.: Growth, Fattening, and Meat Production. With Harry W. Titus 450-468
- Hardy, John I.: The Relation of Nutrition to the Production of Hides and Wool. With Imogene P. Earle 492-500
- Hart, E. B., statement on research in animal industry 1046-1047
- Hartman, A. M.: Deficient and Excess Minerals in Forage in United States 1027-1044
- Hay—
  - alfalfa—
    - feeding to horses and mules 776-777
    - harvested, percentages of leaves at different growth stages 960
  - artificially dried—
    - composition on water-free basis 1000
    - losses 998-1001
  - carotene content and protein digestibility 999
  - clover, feeding to horses and mules 777
  - color, relation to quality 975-976
  - composition, digestibility, and digestible nutrients 994
  - curing—
    - and storing, chemical changes during 965-969
    - comparison of old and new methods 992-993
    - losses 992-1001
  - dried, artificially, effect on nutritive value 979-980
  - drying, costs 979-980
  - feed—
    - constituents, curing losses 996
    - requirement in normal growth of heifers up to 2 years 599
    - value 1015-1016
  - feeding to—
    - dairy calves 613
    - horses and mules 776-778
  - field-cured—
    - composition on water-free basis 1000
    - effect on nutritive values 970-975
    - losses 993-998
    - losses of dry matter and starch equivalent, distribution 994
  - fresh, composition on water-free basis 1000
  - grades, relation to nutritive values 975-979
  - grinding, effect on nutritive values 980-981
  - harvesting methods, processing, and storing, effects on nutritive value 965-970
  - leaf meals, grinding, effect on nutritive values 980-981
  - legumes, leafiness, relation to quality 976-977
  - meals, ground, advantages 980-981
  - miscellaneous, feeding to horses and mules 777
  - nutritive value—
    - factors affecting 970-981
    - suggestions for research 1063
  - oat and vetch, composition, comparison with silage 1014
  - plants, stem texture, effect on nutritive value 978-979
  - production, in United States, value 956-957
  - quality—
    - effect of excessive drying 999
    - factors affecting 975
  - soybean, feeding to horses and mules 777
  - spontaneous heating, effect on nutritive value 969-970
  - sun-cured, feed value, comparison with artificially-dried 980
  - time of cutting, relation to quality 978
  - timothy—
    - feeding to horses and mules 776
    - harvested, composition of dry matter, at different stages of maturity 959
    - proportion of leaves, stems, heads, and protein content and different growth stages 961
  - unsound, description 978
  - use as—
    - feed, limitation 990-991
    - supplement for pasturage in livestock feeding 939-942
  - vetch and oat, composition, comparison with silage 1014

Page
- Haymaking—
  - losses—
    - and silage losses. J. A. LeClerc 992-1016
    - summary 91-93
  - old and new methods, data 993-1001
- Health—
  - claims, fraudulent, detection 141
  - foods, fallacy 11-12
  - good, relation to proper nutrition, studies 321-336
  - of farm animals—
    - factors affecting. Louis L. Madsen 431-449
    - maintenance, factors affecting, summary 47-48
  - relation to food—
    - and food functions. Lela E. Booher and Callie Mae Coons 100-123
    - consumption and food functions, summary 7-10
- Heat—
  - production per ton of fruit per day at several temperature levels 352
  - requirements of animals 436-438
- Heifers—
  - dairy—
    - cost of raising, factors affecting 622-623
    - growth and production, relation of ration and age at first calving 619-623
    - growth, effect of ration 620
    - live weight and height, birth to 7 years 625
    - raising 615-623
  - feed requirements for normal growth 599
  - feeding—
    - before and after calving 618-619
    - guides 599
  - 6 months to 2 years, feeding 615-618
- Hemeralopia, result of vitamin A deficiency 702
- Hemicellulose, function in diet 155-156
- Hemoglobin—
  - formation 209
  - standards for men and women 205-206
- Hens, feeding iodine concentrate 212
- Herbage, nutritional value, research 952-954
- Hides—
  - production, relation to nutrition—
    - John I. Hardy and Imogene P. Earle 492-500
    - summary 52
  - quality, factors influencing 494-496
- Hogs—
  - feed combinations, suggestions 739
  - feeding—
    - hay and concentrates to supplement pasturage 942
    - methods 738-741
    - practices 723-745
  - nutritive requirements 706-722
  - *See also* Swine.
- Home Economics, Bureau of—
  - vitamin A experiments 24-25
  - vitamin A requirements project 227-229
- Homemaker, modern, necessary information—
  - Miriam Birdseye 372-379
  - summary 40
- Homemakers, new skills, necessity for 375-377
- Homemaking, adaptation to modern methods 372-379
- Hormones—
  - ovarian, influence on mammary gland development 686
  - relation to milk secretion—
    - M. H. Friedman and C. A. Cary 685-698
    - summary 66-67
- Horse serum, substitution for colostrum, experiments 506
- Horses—
  - calcium requirements 770-772
  - digestion in, description 424, 427
  - draft, fattening for market 785-786
  - energy requirements 767-769
  - feeding—
    - hay and concentrates to supplement pasturage 942
    - under work conditions, methods 780-781
  - feeds and economical feeding practices 773-786
  - idle, wintering 782-783
  - iodine requirements 772-773
  - light, fattening for market 786

Horses—Continued. Page
  - mastication habits 422
  - mineral requirements 769-770, 779-780
  - Morrison's feeding standards 765
  - nutrition—
    - Earl B. Krantz and S. R. Speelman 763-786
    - summary 75-77
  - nutritive requirements 764-773
  - phosphorus requirements 770-772
  - prehensive habits 419-420
  - preparation for spring work 783
  - protein requirements 764-767
  - salivary secretion and swallowing habits 423
  - salt requirements 772
  - vitamin requirements 773, 779-780
  - water requirements 779
  - work, daily rations, suggestions 782
- Hosterman, W. H.: The Nutritive Value of Harvested Forages. With T. E. Woodward, P. V. Cardon, and E. W. McComas 956-991
- Howe, Paul E.:
  - Can Food Habits Be Changed? 131-138
  - Some Effects of Nutritional Levels 469-475
- Human—
  - food requirements, carbohydrates, fats, and energy. Helen S. Mitchell, Jane O. Lease, and Nancy B. Morey 152-172
  - nutrition. *See* Nutrition, human.
- Humans—
  - food requirements, summary 13-30
  - physical development, relation to food 97-99

- Idaho, forage crops, iodine deficiency 1036
- Illinois Agricultural Experiment Station, experiments with poultry growth and weights 457-458
- Income—
  - distribution, problem. Marius Farioletti 385-392
  - fluctuations, relation to dietary habits 40-44
  - levels, relation to type of diets, statistics 316-320
  - national—
    - distribution and maldistribution 387-388, 389-390
    - distribution, relation to employment 388-389
    - size and increase, relation to diet 386-387
  - size and distribution, relation to food consumption programs 401
- Indiana Agricultural Experiment Station, investigations of enzymes in hay 966
- Infants—
  - copper requirements 210
  - iron requirements 200-202
  - newborn, calcium demands 193
  - vitamin B_1 requirements 234
  - vitamin C—
    - daily allowance 255
    - requirements 244-246
  - vitamin D—
    - daily allowances 259
    - requirements 257-258
- Iodine—
  - and fluorine. Margaret Cammack Smith 211-213
  - concentrate, feeding to dairy cow and hen 212
  - content in milk 647-648
  - deficiency in forage crops, by States 1006-1038
  - function in human body 9, 113-114
  - human requirements 21, 212
  - occurrence in foods 279-280
  - requirements of—
    - dairy cattle 587, 632
    - horses and mules 772-773
- Iowa—
  - Agricultural Experiment Station, experiments with vitamin E 260
  - forage crops, iodine deficiency 1036
- Irish, Frederick W.: Vitamin D 255-259
- Iron—
  - content of—
    - foods, analysis, shortcomings 282
    - foods, analysis, technical notes 285
    - milk 647
  - deficiency—
    - human blood, causes and remedies 200-208
    - in Massachusetts 1039
  - foods rich in, list 277-278
  - function in human body 9, 112-113, 198-199

Iron—Continued. Page
human requirements—
Mabel A. Dickson 197–211
summary 19–21
needs of women during pregnancy and lactation 208
requirements of dairy cattle 632
utilization by copper for hemoglobin 209

JARDINE, JAMES T., statement on research in animal nutrition 1046
Johnson grass, feeding to horses and mules 776
JONES, D. BREESE: Protein Requirements of Man 173–186
JOSS, EDWARD C.: United States Meat Inspection 355–360

Kansas, forage crops, phosphorus deficiency 1031
KAUFFMAN, W. R.: Composition of the Principal Feedstuffs Used for Livestock. With N. R. Ellis and C. O. Miller 1065–1074
KELLOGG, CHARLES E.: Nutrition of Fur Animals 871–892
KELLY, ERNEST: Supervision and Inspection of Milk 360–363
Kidney, source of riboflavin in diet 264
Kids—
feeding, recommendations 512–513
young, nutrition 501–509, 512–513
KLINE, O. L.:
The Pellagra-Preventive Factor 266–271
Vitamin B_1 229–235
KNAPP, BRADFORD, Jr.: Nutritional Requirements of Beef and Dual-Purpose Cattle. With W. H. Black and J. R. Douglas 519–543
KRANTZ, EARL B.: Nutrition of Horses and Mules. With S. R. Speelman 763–786
KRAUS, E. J.: Sources and Cycles of the Nutritive Elements 405–417

Lactalbumin, source 695
Lactase, function in digestion 429
Lactation—
relation to glands, hormones, and blood constituents 66–67
See also Milk secretion.
Lactoflavin. *See* Riboflavin.
Lactoglobulin, source 695
Lactose—
content of milks 506–507
secretion, research 694–695
Lamb, source of copper 210
Lambs—
fattening, feed requirements 749–752
feeding—
future outlook 756–757
recommendations 513–514
hothouse, feeding 751–752
young, nutrition 501–509, 513–514
See also Ewes; Sheep.
Lead, occurrence in human body, and toxicity 220
League of Nations—
Health Organisation—
recommendations of cod-liver oil dosage 259
standards of energy requirements 166
Technical Commission of the Health Committee, report on protein requirement 18, 183–184
Technical Commission on Nutrition—
recommendations for iron in diet 204
recommendations for mineral requirements 19
recommendation of calcium requirement for human maintenance 191, 192, 194
report on standards 166–169
vitamin C allowance for adults 247
LEASE, JANE G.: Fats 157–160
LECLERC, J. A.: Losses in Making Hay and Silage 992–1016
Legumes—
comprising forage in grazing regions 927–928
forage, nutritive values 962–964
Life cycles, interrelationships 407–408
Light—
effect upon riboflavin 262
production of carotene and chlorophyll 222

Page
Linseed meal, feeding to horses and mules 775
Lipase, function in digestion 429
Literature cited 1075–1142
Lithium, occurrence in human body 219
Liver—
animal, value to eyesight, knowledge of ancients 221
calf—
source of copper 208, 210
source of iron 201, 202, 208
fish, oils, vitamin A content 222, 224
source of riboflavin 264
value in cure of pellagra 268, 269
Livestock—
breeding records 478–479
cobalt deficiency, causes and control 215–216
fat requirements, limited knowledge 1056–1057
feeding—
hay and concentrates to supplement pasturage 937–940
importance of composition of feedstuffs 1065–1074
management, relation to health and disease, suggested research 1055–1056
on southern forest ranges, factors affecting 951–952
pasturage as supplement to hay and concentrates 940–944
pasture and range. P. V. Cardon, W. R. Chapline, T. E. Woodward, E. W. McComas, and C. R. Enlow 925–955
fertility—
relation to diet summary 50–52
studies 476–482
food requirements in relation to health 431–433
genetics, relation to nutrition 469–475
grazing methods 932–935
health and disease, relation to nutrition, suggested research 1055–1056
mineral requirements, limited knowledge 1057
nutrition—
miscellaneous factors affecting 1058–1059
relation to health and disease, suggested research 1055–1056
requirements, related problems 1051–1052
research needs 1050–1064
what we need to know. O. E. Reed 1045–1064
nutritional levels, significance 469–475
nutritive values of range plants 947–948
overfeeding, results 443–446
pasturage, nutritive values 934–944
pasture and range feeding—
suggestions for research 1060–1062
summary 87–89
principal feedstuffs used for, composition. N. R. Ellis, W. R. Kauffman, and C. O. Miller 1065–1074
production, relation to maintenance of range forage 948–951
protein requirements, limited knowledge 1056
reproduction and nutrition 482–491
reproductive failures—
Ralph W. Phillips 476–482
causes 476–477
causes, relative importance 479–482
occurrence 478–479
undernutrition, effects 446–448
vitamin requirements, limited knowledge 1057–1058
yields, relation to forage yields, correlations 954–955
young dairy, practical feeding and nutritional requirements. Joseph B. Shepherd and H. T. Converse 597–638
Longevity, relation to food habits 120–121
Louisiana, forage crops—
calcium deficiency 1035
phosphorus deficiency 1031–1032

MADSEN, LOUIS L.: Factors Affecting Maintenance Nutrition, Feed Utilization, and Health of Farm Animals 431–449
Magnesium, occurrence—
and results of deficiency in animals and man 216

Magnesium, occurrence—Continued. Page
  in foods 278
Maltase, function in digestion 429
Mammary gland, development 686–687
Man, protein requirements, D. Breese Jones 176–186
Manganese—
  content of milk 647
  content of poultry feedstuffs 841
  effect on hatchability of eggs 797–798
  occurrence—
    in foods 279
    uses, and effects 215
  requirements of—
    chickens and turkeys 816, 818
    gallinaceous upland game birds 918
Mares, brood, feeding and nutritive requirements 783–784
Marine products—
  digestible protein and digestible nutrient content for cattle, sheep, and swine, determinations 1072
  feed value 1023, 1024, 1025–1026
  percentage composition used in animal feeding 1068–1069
Martens, characteristics and studies 890–891
Massachusetts—
  cobalt deficiency 1039
  forage crops, iron deficiency 1039
Maynard, L. A., statement on research in animal nutrition 1047–1048
McComas, E. W.:
  Pasture and Range in Livestock Feeding. With P. V. Cardon, W. R. Chapline, T. E. Woodward, and C. R. Enlow 925–955
  Nutritive Value of Miscellaneous Feeds. With Thompson E. Woodward 1017–1026
  The Nutritive Value of Harvested Forages. With T. E. Woodward, W. H. Hosterman, and P. V. Cardon 956–991
McLester, James S., foreword 2
Meals—
  planning for nutritive values, factors affecting 329–332
  plans, analysis 134–135
Meat—
  animals, inspection procedure 357
  contributions to diet 326–327
  dressed, chemical composition 458–460
  edible—
    composition, estimation 467–468
    proportion in meat animals 462–464
  exports and imports, inspection certificates 358–359
  fat distribution, significance 460–462
  feeding to dogs, recommendations 856–859
  grade labeling for consumers 368–369
  inspection—
    administration 357–359
    Federal, description 38
    Federal, summary 38
    miscellaneous services 359
    purpose 355
    scope 356
    United States. Edward C. Joss 355–360
  lean tissue, fat content 461–462
  processing plants, requirements for carrying out Federal inspection 357
  production, relation to growth and fattening. O. G. Hankins and Harry W. Titus 450–468
  products, inspection procedure 357–358
  source of—
    copper 208, 210
    iron 202, 204, 208, 278
    phosphorus 277
  spoilage prevention 345–346
  storage changes 353–354
Meigs, E. B.:
  Statement on research in animal nutrition 1052, 1054–1055, 1058
  The Feeding of Dairy Cows for Intensive Milk Production in Practice 566–591
Men—
  calcium utilization 192
  copper requirements 210
  energy allowances, recording schedule 168–169
  food energy, daily allowance suggestions 172
  iron requirements 204–205
Men—Continued. Page
  phosphorus requirement 194
  weight averages according to height and age 161
Menus, analysis 134–135
Mercury, occurrence in human body 219–220
Metabolism—
  basal, of animals, studies 437
  copper and iron requirements, studies 21
  factors affecting 102
  human, function of vitamin B_1 in 230, 232
Michigan—
  Agricultural Experiment Station and Bureau of Animal Industry, meat animal experiments 454–455
  forage crops—
    iodine deficiency 1036
    phosphorus deficiency 1032
Micro-organisms—
  classification and action 341–342
  function in silage formation 1005, 1006
  in foods—
    and food preservation. Harry E. Goresline 341–349
    summary 36–37
  use in—
    food preservation and processing 37, 346–349
    manufacture of milk products 349
    wine and beer production 347
Milk—
  carbohydrate content 506–507
  care in home 363
  composition—
    and feed value 1023–1024
    and nutritive value 506–508
    breed differences 641–642
    changes from colostrum to normal 645
    differences in periods between milkings 644
    differences of different species 639–641
    differentiating factors 641–645
    effect of diet 645
    effect of gestation and disease 645
    for five breeds of cows 641
    individual differences 644
    influence of successive phases of lactation period 645
    research 699–705
    variations in. P. A. Wright, E. F. Deysher, and C. A. Cary 639–648
    variations in different parts of udder 644–645
    variations, summary 62–63
  constituents, minor inorganic 646–648
  contributions to diet 326, 327
  copper content 646–647
  drugs in, transmission through blood stream of cow 648
  energy value, relation to fat and protein content 642–644
  fat—
    content 506–507
    content, relation to protein and energy values 642–644
    content, variation during milking 644
    source 697–698
  feed—
    flavors and odors, transmission through blood stream 648
    requirement in normal growth of heifers up to 2 years 599
  goats', quality and nutritional value 758, 761
  human—
    nitrogen content 640
    qualities and comparison to cow's milk 639
    vitamin C content 244, 245
  in nutritional research, a sketch of progress. C. A. Cary 699–705
  inspection—
    maintenance of sanitation standards 361–363
    value in fraud prevention 361
  iodine content 647–648
  iron content 647
  lactose content 506–507
  limited quantities, combined with dry grain or dry-fed calf meal, feeding to dairy calves 608–609
  mammalian, composition 640
  manganese content 647

Milk—Continued. Page

- market, State and municipal requirements 360
- mineral—
  - ash, composition 646
  - constituents 645–648
  - content 506, 507
- nitrogen content 640
- nutritional—
  - deficiencies, source of knowledge 703–705
  - value, uniformity of standards 360–361
- of goats, quality and nutritional value 758, 761
- ordinances, necessity in maintenance of sanitation standards 361–362
- processing plants, inspection as sanitary measure 362–363
- production—
  - energy requirement per pound of milk 656
  - in dairy cows, intensified by feeding practices, summary 57–59
  - intensive, in practice, feeding dairy cows for, Edward B. Meigs 566–596
- presence of vitamins in, summary 64–66
- protein sources, arrangement according to value 666
- vitamins in. C. A. Cary 668–684
  - yearly, by breeds of cows having official records 642
- products—
  - composition and feed value 1024, 1026
  - digestible protein and digestible nutrient content for cattle, sheep, and swine, determinations 1072
  - percentage composition used in animal feeding 1068–1069
  - role of micro-organisms 349
  - value in calf diet 602
- protein—
  - content 506, 507–508
  - content relation to fat and energy values 644
  - source 695–697
- quantities for dairy-calf ration 603
- relation between protein, fat, and energy values 643
- secretion—
  - effect of glands, hormones, and blood constituents, summary 66–67
  - effect of pituitary extracts 687, 688–689, 691
  - energy-utilization, experiments 650–656
  - feed energy and feed protein in, utilization, summary 63–64
  - onset and maintenance, factors governing 687–691
  - protein utilization 656–667
  - relation to glands, hormones, and blood constituents. M. H. Friedman and C. A. Cary 685–698
  - utilization of feed energy and protein. C. A. Cary 649–667
  - *See also* Lactation.
- skim—
  - composition and total digestible nutrients 602
  - digestible nutrients and feed value per 100 pounds, comparison with fresh skim milk 602
  - dried, reconstituted, feeding to dairy calves 607–608
  - feeding to dairy calves after starting on whole milk 604–605
- spoilage prevention 345
- substitution of—
  - calf meals for, in feeding dairy calves 609–612
  - grain for, in feeding dairy calves 609
- sugar, source 694–695
- supervision and inspection—
  - Ernest Kelly 360–363
  - summary 38–39
- unknown factors, discoveries 699–701
- value in—
  - diet as protective food 380–381
  - nutritional research, progress, summary 68–69
- vitamin A content 222, 224
- vitamins in—
  - and in milk production. C. A. Cary 668–684
  - summary 64–66
- whole—
  - composition and total digestible nutrients 602

Milk—Continued. Page

- whole—continued.
  - digestible nutrients and feed value per 100 pounds, comparison with fresh skim milk 602
  - elimination from starting ration of dairy calves 605
  - later feed of dairy calves, impracticability 605–606
  - value in first feeding of dairy calves 602–604
- zinc content 647

MILLER, C. O.: Composition of the Principal Feedstuffs Used for Livestock. With N. R. Ellis and W. R. Kauffman 1065–1074

Mineral-supplement mixtures, for horses and mules, recommendations 779–780

Minerals—

- content of—
  - feeds 531–533
  - foods 275–285
  - foods, analyses, technical notes 283
  - foods, analysis, shortcomings 280–282
  - milks 506, 507, 645–648
  - plants 408–410
- deficiency in—
  - diet, misleading advertising 142
  - rations, effect on cattle 530–531
- effect on hatchability of eggs 797–798
- functions in—
  - animal body 529–530
  - human body 8–10, 111–115
- human requirements 187–220
- in forage—
  - deficiency and excess. A. M. Hartman 1027–1044
  - key list of correspondents 1042–1044
- in poultry diet, nature and value 822–823
- needs of man—
  - Henry C. Sherman, Mabel A. Dickson, Margaret Cammack Smith, and Esther Peterson Daniel 187–220
  - summary 18–21
- nutritionally essential, deficiencies by States 1031–1042
- requirements of—
  - animal reproduction 487–488
  - beef cattle 529–538
  - dairy cattle 585–589, 631–632
  - dogs 853–854
  - egg production 805–806
  - gallinaceous upland game birds 916–918
  - horses 769–770, 779–780
  - livestock, limited knowledge 1067
  - mules 769–770, 779–780
  - poultry 814–816
  - swine 718–720
- trace elements, identification, occurrence, and effects 213–220

Minks—

- characteristics 885–886
- diets used in metabolism studies 888
- digestion trials at Cornell University, results 886–889
- feeding, recommendations 890
- vitamin A reserve 886

Minnesota—

- Agricultural Experiment Station, silage experiments 558
- forage crops—
  - iodine deficiency 1036
  - phosphorus deficiency 1032

MITCHELL, H. H., statement on research in animal industry 1049, 1050–1051

MITCHELL, HELEN S.:

- Carbohydrates 152–157
- Food Fads, Facts, and Fancies 139–144

Moisture—

- effect on quality of silages 985–987
- effect on yield and nutritive value of grasses 935

Molasses—

- addition to silage, purpose 988
- use in making silage 546–547, 1010

Molds—

- cause of organic decomposition 341–342
- growth—
  - in eggs, preventive methods 344–345

- Molds—Continued. Page
  - growth—continued.
    - in fruit juices, preventive measures 342
    - on fruits, preventive measures 342
    - on vegetables, preventive measures 343
- Molybdenum, occurrence in human body 220
- Montana, forage crops—
  - iodine deficiency 1036
  - phosphorus deficiency 1033
- MOREY, NANCY B.: Energy Requirements 160–172
- MORRISON, F. B., statement on research in animal industry 1047
- Mules—
  - calcium requirements 770–772
  - energy requirements 767–769
  - feeding under work conditions, methods 780–781
  - feeds and economical feeding practices 773–786
  - idle, wintering 782–783
  - iodine requirements 772–773
  - mineral requirements 769–770, 779–780
  - nutrition—
    - Earl B. Krantz and S. R. Speelman 763–786
    - summary 75–77
  - nutritive requirements 764–773
  - phosphorus requirements 770–772
  - preparation for spring work 783
  - protein requirements 764–767
  - salt requirements 772
  - vitamin requirements 773, 779–780
  - water requirements 779
  - work, daily rations, suggestions 782

- Nebraska, forage crops—
  - calcium deficiency 1035
  - iodine deficiency 1037
  - phosphorus deficiency 1033
  - selenium excess 1039
- NELSON, E. M.: Vitamin E 259–261
- Nervous system, influence on lactation 690
- NESTLER, RALPH B.: Feeding Requirements of Gallinaceous Upland Game Birds 893–924
- Nevada, forage crops—
  - iodine deficiency 1037
  - phosphorus deficiency 1033
- New Mexico—
  - Agricultural Experiment Station, feeding experiments 548
  - forage crops, phosphorus deficiency 1033
- New York Association for Improving the Condition of the Poor, work in calcium nutrition 189–190, 193
- New Zealand, livestock disease caused by cobalt deficiency, and control 215–216
- Nickel, occurrence in human body 219
- Nicotinic acid—
  - amide—
    - efficacy in cure of pellagra 269, 271
    - remedy for blacktongue of dogs 268
    - efficacy in treatment of pellagra 267
    - function in—
      - human body 119
      - control of pellagra 268–269
  - sources and value in control of pellagra 291
- Night blindness, cause and control 223, 226–227
- Nitrogen—
  - content of dried grass 996
  - supplies, carbohydrate relationships, types 412–415
  - value in plant fertilizers 412
- North Dakota, forage crops—
  - iodine deficiency 1037
  - phosphorus deficiency 1033–1034
- Nucleinase, function in digestion 429
- Nutrients—
  - disgestible, daily—
    - maintenance requirement of cattle 520
    - requirement for growth and fattening of beef cattle 524
  - essential—
    - food sources 132–134
    - requirements of swine 708–722
  - lacking in plants, cause and effects 410
- Nutrition—
  - adequate, relation to agricultural surplus 391–392

- Nutrition—Continued. Page
  - and reproduction. M. H. Friedman and W. A. Turner 482–491
  - animal 405–1142
  - better, national goal, summary 40–44
  - birds, upland game, gallinaceous, requirements, summary 86–87
  - cattle, beef and dual-purpose, requirements—
    - W. H. Black, Bradford Knapp, Jr., and J. R. Douglas 519–543
    - summary 54–56
  - cattle, dairy, requirements 624–638
  - dairy stock, young, requirements—
    - practical feeding. Joseph B. Shepherd and H. T. Converse 597–638
    - summary 60–63
  - dogs, requirements, summary 81–82
  - fads and frauds, scope 140–144
  - fur animals, summary 84–86
  - good, planning—
    - Hazel K. Stiebeling and Faith Clark 321–340
    - summary 34–36
  - horses—
    - and mules. Earl B. Krantz and S. R. Speelman 763–786
    - summary 75–77
  - human 97–402
  - human—
    - calcium and phosphorus requirements. Henry C. Sherman 187–197
    - development from tradition to a science. Louise Stanley 97–99
    - development from tradition to a science, summary 6–7
  - improvement as national goal. Hazel K. Stiebeling, Marius Farioletti, F. V. Waugh, and J. P. Cavin 380–402
  - livestock. *See* Livestock, nutrition.
  - maintenance—
    - by farm animals, factors affecting. Louis L. Madsen 431–449
    - essential to vital functions 433–443
    - of farm animals, factors affecting 47–48
  - mules, summary 75–77
  - national level, improvement problem. Hazel K. Stiebeling 380–385
  - plane—
    - effect on wool fiber 496–497
    - relation to reproduction 482–485
  - poultry, practical requirements—
    - Harry W. Titus 787–818
    - summary 77–79
  - relation to production of hides and wool—
    - John I. Hardy and Imogene P. Earle 492–500
    - summary 52
  - science of—
    - development from tradition. Louise Stanley 97–99
    - value and importance 3–5
  - sheep requirements 746–749
  - swine, requirements—
    - N. R. Ellis and J. H. Zeller 706–722
    - summary 69–70
  - very young animals—
    - Imogene P. Earle 501–518
    - summary 52–54
  - vitamin C, state of, judging 239–242
  - vitamin requirements 23–30
  - *See also* Feeding.
- Nutritional—
  - deficiencies, in milk, source of knowledge 703–705
  - goal—
    - attainment, role of agriculture 400–402
    - relation to agricultural adjustment programs. J. P. Cavin 396–402
  - levels, some effects. Paul E. Howe 469–475
  - research, value of milk, a sketch of progress. C. A. Cary 699–705
- Nutrive elements, sources and cycles—
  - E. J. Kraus 405–417
  - summary 44–45
- Nuts—
  - byproducts, feed value 1018–1023
  - source of—
    - phosphorus 277
    - protein in feeds 1018–1023

Oats— Page
  feeding to horses and mules 774
  in hay and silage, comparative composition 1014
Ohio Agricultural Experiment Station, feeding experiments 560
Oilseed byproducts, protein content and feed value 1018, 1019
Orange juice, source of—
  iron 201, 202
  vitamin C 240, 246, 248
Oranges, source of carotene 225
Oregon, forage crops—
  iodine deficiency 1037–1038
  phosphorus deficiency 1034
Ox—
  digestion in, description 424, 427
  mastication habits 422–423
  prehensive habits 419–420
  salivary secretion and swallowing habits 423
Oysters, source of—
  copper 208, 210
  iron 204

Palmer, L. S., statement on research in animal nutrition 1048–1049
Pancreatic juice, function in digestion 427
Partridges—
  feeding requirements 900, 902, 910
  range and description 895–896
Pasteurization, milk, for spoilage prevention 345
Pasteurizing plants, milk, inspection as sanitary measure 362–363
Pasturage—
  feeding to dairy calves 615
  nutritive value to livestock 935–944
  use to supplement hay and concentrates in livestock feeding 942–944
Pasture—
  feeding, suggestions for research 1060–1061
  in livestock feeding—
    P. V. Cardon, W. R. Chapline, T. E. Woodward, E. W. McComas, and C. R. Enlow 925–955
    summary 87–89
Pastures—
  distinction from ranges 926–929
  effects of soil and fertilizers on, research 952–955
  farm—
    economic importance and major uses 929–930
    for livestock 929–944
  kinds, classification 930–932
  management, effect on nutritional value 935–939
  nutritive value, influence of—
    management practices 935–939
    physical factors 935
  permanent, temporary, and supplemental scheme 932
  use by horses and mules as supplementary feed 778
  value in swine production 741–742
Pea-cannery waste, protein content and feed use 1020
Peaches, source of carotene 225
Peanut byproducts, protein content and feed value 1019
Peas, source of iron 201, 202
Pellagra—
  cause and—
    geographical extent 266–267
    prevention 30
  control by foods containing nicotinic acid 291
  prevention and cure 269–271
  preventive factor—
    O. L. Kline 266–271
    research 702–703
  relation to diet deficiency 119
  similarity to blacktongue in dogs 267
  symptoms 267–268
Pepsin, function in digestion 427
Perosis—
  cause and symptoms in poultry 829
  in chickens, cause 797
Pheasant chicks, feeding practices 906–907, 921–922
Pheasants—
  feeding requirements 900, 902, 903, 909–911, 924
  range and description 896

Page
Phillips, Ralph W.: Reproductive Failures in Livestock 476–482
Phosphoric acid, combination with vitamin B_1 232
Phosphorus—
  adult needs—
    comparison with calcium requirements 194–197
    for normal maintenance 194–195
  assimilation in—
    dairy cows, factors affecting 587
    humans, function of vitamin D 193
  balance studies with children 196
  content of—
    foods, analysis, shortcomings 282
    poultry feedstuffs 841
  deficiency—
    in forage crops, by States 1031–1035
    relation to food utilization 441–442
  foods rich in, list 277
  function in human body 9, 111–112
  human requirements 19, 194–197
  metabolism, role of vitamin D 255–256
  needs of women during pregnancy and lactation 195
  requirement, source in feeds 533–538
  requirements—
    for growing and fattening steers 537
    of chickens 814, 818
    of children 195–196
    of dairy cattle 631–632
    of dairy cows 586–587
    of gallinaceous upland game birds 917–918
    of growing turkeys 814, 818
    of horses and mules 770–772
    of human nutrition. Henry C. Sherman 187–197
Pigeon—
  digestion in, description 425
  milk, composition 425–427
  prehensive habits 421
Pigments, yellow, association with vitamin A 222, 224, 225
Pigs—
  body composition, relation to nutritional needs 707–708
  breeding, special feeding practices 743
  digestion in, description 424, 427
  feeding—
    during gestation period 743–744
    recommendations 514–516
  growth and fattening, special feeding practices 742–743
  mastication habits 422
  prehensive habits 419–420
  salivary secretion, description 423
  suckling, special feeding practices 742
  young, nutrition 501–509, 514–516
Pituitary—
  extracts—
    effect on milk production 687, 688–689, 691
    milk-stimulating, relation to other body processes 691–693
  gland, function, relation to diet 693–694
Plant—
  foods—
    degree of maturity, relation to vitamin content 292
    preservation and storage, effect on vitamin content 292–293
  species, principal, in United States 926
  tops, care and management 410–411
  varieties, effect on vitamin content 291–292
Plants—
  capacity for absorbing and utilizing mineral nutrients 410–411
  carbohydrate reserves, relation to fertilizers 411–412
  growth and development, mineral elements necessary 409–410
  mineral content 408–410
  nutritive values, dependence on water supply 410
  poisonous to sheep, kinds 756
  range—
    effects of soil amendments 952–954
    nutritive value to livestock 947–948

Plants—Continued. Page
- storage of, energy processes 406-407
- vitamin content, effects of varietal differences, soil, and climate 291-292

Polyneuritis, symptoms, cause, and cure 231
Polypeptides, function in synthesis of body proteins 695-696
Pork—
- products, quality, relation to feeds 732-733
- soft, causes 732-733

Potassium, occurrence in foods 278
Potatoes, source of iron 202
Poultry—
- conditioners, use, disadvantages 826
- contributions to human diet 326-327
- fattening, nutritive requirements 817-818
- feeding—
  - management, recommendations 837-838
  - practical, summary 79-81
  - systems, description and recommendations 829-832
- feedstuffs—
  - calcium content 841
  - composition, analysis 839-840
  - digestibility in chicken 842
  - manganese content 841
  - phosphorus content 841
  - vitamin content 842-843
- growth, nutritive requirements 807-817, 818
- houses, lighting, recommendations 839
- mineral requirements 814-816
- nutritive requirements, practical—
  - Harry W. Titus 787-818
  - summary 77-70
- practical feeding. Harry W. Titus 819-842
- vices, causes and prevention 826-827
- vitamin requirements 816-817, 818
- water supply, recommendations 825-826
- *See also* Fowl; *also* under specific kinds.

Prolactin, effect on milk secretion 692, 693
Protein—
- absorption by suckling animals 508
- concentrates, requirements of gallinaceous upland game birds 913-914
- content of—
  - foods 274-275
  - milks 506, 507-508
- deficiency—
  - in diet, prevalence 184-185
  - quantitative or qualitative effect on farm animals 438-440
- definition 175
- digestibility—
  - differences 178-179
  - in artificially dried hay 999
- effect on—
  - hatchability of eggs 793-794
  - heat production of animals 434-436
  - reproduction 488-490
- feed, utilization in milk secretion—
  - C. A. Cary 649-667
  - summary 63-64
- feeding to swine 734-736
- function in human body 107-109, 173-175
- high content in diet, effects 185-186
- human requirements 8, 17-18, 173-186
- in milk, source 695-697
- in poultry diets, nature and value 821-822
- levels, in feeds, experiments 662-667
- of plant origin, effect on chick embryonic mortality 799
- percentages in grain mixtures for young dairy stock 614
- quantitative requirement in human diet 180-182
- requirements of—
  - animals 436-438
  - beef cattle 525-528
  - chickens 811-814
  - dairy cows 579-580
  - dogs 845, 849-852
  - egg production 804-805
  - horses and mules 764-767
  - livestock, limited knowledge 1056
  - man. D. Breese Jones 173-186
  - swine 715-718
  - turkeys 814, 818
  - wool production 498-499

Protein—Continued. Page
- source of heat and energy 436
- supplementary relationship 179-180
- utilization—
  - in milk secretion 656-667
  - relation of inadequate food intake to energy production 440-441
- variation in nutritive value 175-178

Prunes, source of iron 201, 202
Pullets—
- adaptation to protein diet, relation to hatchability of eggs 798
- age, effect on hatchability of eggs 798-799
- economic maintenance requirements 801

Puppies—
- feeding, recommendations 516-518, 857-859, 864-866
- young, nutrition 501-509, 516-518

Purchasing power, relation to employment and income distribution 389-390
Pyorrhea, cause and cure 251-252

Quail—
- chicks, feeding practices 923-924
- feeding requirements 900, 902-906, 909, 910
- range and description 895-896

Rabbits, domestic, feeding 891-892
Rainfall, effect on yield and nutritive value of grasses 935
Range—
- areas, extent, and description 944-952
- distinction from farm pastures 926-927
- feeding—
  - of livestock, summary 87-89
  - suggestions for research 1061-1062
- forage—
  - maintenance, relation to livestock production 948-951
  - production, types and species 946-947
- forest, southern, management requirements for livestock grazing 951-952
- in livestock feeding. P. V. Cardon, W. R. Chapline, T. E. Woodward, E. W. McComas, and C. R. Enlow 925-955
- major uses 945
- western, extent and significance 944

Rat—
- experimental value 145-151
- white—
  - as contributor to science. M. H. riedman 145-151
  - place in science, summary 12-13

Rations—
- allotment to dairy cows, summary 59-60
- fattening, for steers 549-550, 558-562
- for—
  - brood mares, requirements 783-784
  - dairy cows, amounts required, determination 570-571
  - dairy cows, figuring. T. E. Woodward 592-596
  - dairy heifers, effect on growth 620
  - fattening lambs, types 750-752
- mineral-deficient, effect on cattle 530-531
- requirements for—
  - pregnant ewes 753
  - range sheep 754-756
- selection for—
  - horses and mules 781-782
  - swine 736-738
- special, for swine 742-744
- types fed to milk goats 760-761
- well-balanced, for swine, requirements 708-720
- *See also* Feeds.

Reed, O. E.: What We Need to Know in Livestock Nutrition 1045-1064
Rennin, function in digestion 427
Reproduction—
- and nutrition. M. H. Friedman and W. A. Turner 482-491
- dietary requirements, exceptions 490-491
- failures in livestock. Ralph W. Phillips 476-482
- fat and protein requirements 488-490
- mineral requirements 487-488
- relation to—
  - diet. Ralph W. Phillips, M. H. Friedman and W. A. Turner 476-499

Page

- **Reproduction—Continued.**
  - relation to—continued.
    - diet, summary 50-52
    - plane of nutrition 482-485
  - vitamin requirements 485-487
- Research, animal nutrition, needs 1050-1064
- Rheumatic fever, control by use of vitamin C 253
- Riboflavin—
  - Lela E. Booher 261-266
  - chemical nature 265-266
  - concentration in milk 676-678
  - content of—
    - cow's colostrum, comparison with later milk 505
    - foods, quantitative determination 264-265
  - deficiency—
    - effects 29-30
    - symptoms in man 265
    - symptoms in rats 262
  - derivation of term 261
  - discovery 261-262
  - distribution in foods 264
  - effect on hatchability of eggs 791, 796-797
  - function in human body 265
  - in eggs, effect on hen's diet 792
  - properties 262-264
  - requirements of growing—
    - chickens 817, 818
    - turkeys 817, 818
  - sources in foods 290
  - *See also* Vitamin B_2; Vitamin G.
- Rice—
  - byproducts, composition and feed value 1021
  - polishing, effect on vitamin B_1 content 232
- Rickets—
  - cause and control 256, 257-258
  - in animals, experimental cause 219
  - in chickens, causes and symptoms 827
  - result of vitamin D deficiency 702
- Roots—
  - digestible protein and digestible nutrient content for cattle, sheep, and swine, determinations 1074
  - feed value 1024-1025
  - percentage composition used in animal feeding 1071
- Roughages—
  - feeding to—
    - dairy cows, importance and methods 568-570
    - horses and mules 776-778
  - miscellaneous, feeding to horses and mules 777-778
- Roup, of chickens, cause and symptoms 827
- Rubidium, occurrence in human body 219
- Ruminants—
  - digestion in, description 424, 427
  - mastication habits 422-423
  - salivary secretion and swallowing habits 423

Page

- Salivary secretion, in domestic animals, comparison 423-424
- Salt—
  - excess in diet of chickens, effects 829
  - iodized, use in goiter belt 212
  - requirements for—
    - dairy cattle 631
    - horses and mules 772
- Samarani method of making silage, description 1011
- Savings accounts, idle, need for redistribution of incomes 389-390
- Schoening, H. W.: The Digestive Processes in Domestic Animals 418-430
- Science—
  - contribution of white rat to. M. H. Friedman 145-151
  - debt to white rat, summary 12-13
- Scurvy—
  - result of vitamin C deficiency 702
  - symptoms and cause 236
- Sea food—
  - source of—
    - calcium 276
    - iodine 212
    - iron 278
    - phosphorus 277
  - value in diet, recommendations 203, 204, 207, 210
- Seeds—
  - byproducts, feed value 1018-1023
  - digestible protein and digestible nutrient content for cattle, sheep, and swine, determinations 1071-1072
  - requirements of gallinaceous upland game birds 911-912
  - percentage composition used in animal feeding 1067-1068
  - source of protein in feeds 1018-1023
- Selenium—
  - damage to animals and occurrence in foods 218
  - effect on hatchability of eggs 798
  - excess in forage crops, by States 1039-1040
  - in forage, effects on livestock 1040-1041
- Serum, blood, of dam, feeding as substitute for colostrum 505-506, 509
- Sheep—
  - digestion in, description 424, 427
  - feeding—
    - future outlook 756-757
    - hay and concentrates to supplement pasturage 942
    - in farm flocks 752-753
    - problems. Damon A. Spencer 746-757
    - problems, summary 72-74
  - grazing habits 746-749
  - mastication habits 422-423
  - nutritive requirements 746-757
  - prehensive habits 419-420
  - range, feeding—
    - on poisonous plants, problems 756
    - requirements 754-756
  - serum, substitution for colostrum, experiments 506
  - *See also* Ewes; Lambs.
- Shellfish, source of—
  - copper 210
  - iron 204
- Shepherd, Joseph B.: Practical Feeding and Nutritional Requirements of Young Dairy Stock. With H. T. Converse 597-638
- Sherman, Henry C.: Calcium and Phosphorus Requirements of Human Nutrition 187-197
- Silage—
  - acid-brown, feed constituents, losses and gains 1009
  - acidity, causes and effects on nutritive values 983-984
  - acids, bases, and dry matter in, comparison with green crops 1014
  - chemical—
    - changes 1013-1014
    - composition, factors affecting 982-983
  - chopping, purpose and methods used 989-990
  - clamp, formation 1007
  - composition 1014-1015
  - curing losses 1001-1016
  - digestible protein and digestible nutrient content for cattle, sheep, and swine, determinations 1074
  - drainage losses 1012-1013
  - early experiments 1004-1005
  - effect of acidity 1011-1012
  - feed—
    - constituents, losses or gains 1008
    - constituents, recovery 1007
    - value 1015-1016
  - feeding to—
    - dairy calves 615
    - horses and mules 778
  - formation—
    - comparison of losses by different methods 1013
    - methods 1009-1011
    - theory 1005-1006
  - forms, effect of type of silo 1006-1009
  - green fruity, feed constituents, losses and gains 1009
  - kinds—
    - dry-matter and carbohydrate losses 1009
    - feed value, and chemical composition 1002-1004
  - losses—
    - and feed values, data 1004-1016
    - and haymaking losses. J. A. LeClerc 992-1016
    - summary 91-93
  - making—
    - methods 987-990

Silage—Continued. Page
  making—continued.
    with molasses 546–547
  moisture content, effect on nutritive value 985–987
  nutritive value—
    factors affecting 981–990
    suggestion for research 1063
  oat and vetch, composition, comparison with hay 1014
  partial drying, effects on quality and odor 989
  percentage composition used in animal feeding 1071
  quality, factors affecting 983–987
  stack, formation 1006–1007
  temperature, effect on nutritive value 985
  tower, formation 1007–1009
  trench, formation 1006–1007
  use as feed, limitations 990–991
Silicon, occurrence in soil, plants, and human tissues 220
Silos—
  history 1001–1002
  types, effect on form of silage 1006–1009
  utilization, factors affecting nutritive values in silage 981–990
Silver, occurrence in human body 219
Skins, animal—
  structure, description 493–494
  utilization and economic value 492–493
Slaughterhouses, requirements for carrying out Federal inspection 357
Smith, Margaret Cammack: Iodine and Fluorine 211–213
Smith, Sybil L.: Vitamin C 235–255
Sodium—
  chloride, requirements for horses and mules 772
  occurrence in foods 278
  requirements of gallinaceous upland game birds 916–917
Soil—
  amendments, effects on range plants 952–954
  effect on—
    nutritive value of forage crops 962
    pastures, research 952–955
    vitamin content of foods 291–292
South, swine production and feeding practices 727–728
South Dakota, forage crops, selenium excess 1040
Sows, with litters, special feeding practices 744
Soybean—
  byproducts, protein content and feed value 1019
  calcium content, analysis, technical notes 283–285
  chemical composition, variations 281, 283–285
  meal, effect on hatchability of eggs 799
  source of riboflavin in diet 264
Spectrograph, use in identifying chemical elements in foods 214
Speelman, S. R.:
  Feeding Dogs 856–870
  Nutrition of Horses and Mules. With Earl B. Krantz 763–786
Spencer, Damon A.:
  Feeding Problems With Goats 758–762
  Feeding Problems With Sheep 746–757
Stanley, Louise: From Tradition to Science 97–99
Starches—
  classification and value in diet 13–14
  function in diet 154
Steapsin, function in digestion 427
Steers—
  body composition at various growth stages 524
  fattening—
    in dry lot 556–562
    on grass 555–556
  feed consumption, hand-feeding versus self-feeding 522–523
  growing and fattening, daily calcium and phosphorus requirements 537
  vitamin A deficiency, symptoms 538–541
  wintering 549–550
Stems, underground, feed value 1024–1025
Stiebeling, Hazel K.:
  Food Habits, Old and New 124–130
  Planning for Good Nutrition. With Faith Clark 321–340

Stiebeling, Hazel K.—Continued. Page
  Present-Day Diets in the United States. With Callie Mae Coons 296–320
  The Problem [Better Nutrition as a National Goal] 380–385
Storage—
  foods, effect on vitamin content 292–293
  methods, food materials 351–354
Strontium, occurrence in human tissues 219
Sucrase, function in digestion 429
Sugar—
  bacterial action in, prevention 346
  chemical classification and function in diet 153–154
  classification and value in diet 13–14
  contribution to diet 327
  milk, source 694–695
Sugar-beet byproducts, composition and feed value 1026
Sulfur, occurrence in foods 280
Sunlight, source of vitamin D 256–257, 259
Sunshine—
  effect on hatchability of eggs 798
  value for poultry 837
Sweetpotatoes, source of carotene 225
Swine—
  energy requirements 710–714
  essential nutrients, requirements 708–709
  feeding—
    for energy and fattening 729–732
    on brewery and distillery byproducts 733–734
    on pasture crops, economic value 741–742
    on protein mixtures 734–736
    practices. J. H. Zeller and N. R. Ellis 723–745
    practices, summary 70–72
    present-day problems 744–745
  growth—
    and weight, factors affecting 708–722
    factors affecting 706–707
  mineral requirements 718–720
  nutritive requirements—
    N. R. Ellis and J. H. Zeller 706–722
    summary 69–70
  production in United States 724–729
  protein requirements 715–718
  vitamin requirements 720–722
  water requirements 722
  See also Hogs.

Teeth—
  calcium—
    and phosphorus requirement 9, 111, 117
    requirements 187–188
  decay—
    prevention in children 259
    relation to diet 121–122
  defects due to vitamin A deficiency 224
  formation, role of vitamin D 255–256
  mottled, cause, extent, and control 212–213
  vitamin A requirement 115
  vitamin C requirement 117
  vitamin D requirement 117
Temperature—
  body, control in farm animals, factors affecting 433–434
  effect on yield and nutritive value of grasses 935
  high, processing, use in silage making, effects 988
Tennessee, forage crops, phosphorus deficiency 1034
Texas, forage crops—
  iodine deficiency 1038
  phosphorus deficiency 1034
Thiamin—
  abundance in nature 289
  chloride, properties 231
  requirement of milk cows 673
  sources in foods 289–290
  See also Vitamin B_1.
Thorium, occurrence in human body 220
Thyroid gland, iodine requirement 9, 113–114
Thyroxin formation, iodine requirement 113–114, 211
Tin, occurrence in human body 217
Tissue, lean of meat, fat content 461–462
Titanium, occurrence in human body 220
Titus, Harry W.:
  Growth, Fattening, and Meat Production. With O. G. Hankins 450–468

Page
Titus, Harry W.—Continued.
  Practical Feeding of Poultry 819–842
  Practical Nutritive Requirements of Poultry 787–818
Tomatoes—
  ripe, source of carotene 225
  value in diet as protective food 380–381
Tonics for chickens, use, disadvantages 826
Toro-Siton method of making silage, description 1011
Trace elements—
  Esther Peterson Daniel 213–220
  definition and importance 214
  field of future research 416–417
  identification 213–214
  list and body requirements 22–23
  occurrence and uses 22–23
  unbalance, effect on farm crops, animals, and man 214–215
Trypsin, function in digestion 427
Tuberculosis, control by use of vitamin C 239, 253, 254
Tubers—
  digestible protein and digestible nutrient content for cattle, sheep, and swine, determination 1074
  percentage composition used in animal feeding 1071
Turkeys—
  feed mixtures, recommendations 836–837
  growth, nutritive requirements 810–811, 814–817, 818
  utilization of feed for growth, comparison with other breeds of poultry 810–811
  wild—
    food requirements 900, 902, 910
    range and habits 896–897
Turner, W. A.: Nutrition and Reproduction. With M. H. Friedman 482–491

Ulcers, peptic, control by use of vitamin C 238, 250, 252–252
Undernutrition, effects on—
  farm animals 446–448
  meat animals 474–475
United States—
  present-day diets in. Hazel K. Stiebeling and Callie Mae Coons 296–320
  swine production areas 724–729
United States Fur Animal Experiment Station—
  fisher research 891
  marten research 891
  mink research 889–890
  silver fox research 879–883
United States Pharmacopoeia, recommendations of cod-liver oil dosage 258, 259
United States Public Health Service, research work with pellagra 267
United States Rabbit Experiment Station, feeding experiments 891–892
United States Range Livestock Experiment Station, Miles City, Mont., feeding experiments 545–546, 547–548, 549

Vanadium, occurrence in foods and tolerance of experimental animals 217
Vegetables—
  contributions to diet 326, 327
  feeding to dogs, recommendations 859
  grade—
    labeling, problems 369
    standards 367
  protection from bacteria and molds 343
  source of—
    calcium 276
    carotene 222, 225
    copper 208, 210
    iron 201, 204, 208, 278
    phosphorus 277
    riboflavin 264
    vitamins in feeds 1024–1025
  storage changes 354
  value in diet as protective foods 380–381
Vetch, in hay and silage, comparative composition 1014
Vinegar making, role of bacteria 347–348

Page
Virginia, forage crops—
  calcium deficiency 1035
  phosphorus deficiency 1034–1035
Vitamin—
  content of—
    colostrum 505
    eggs 800
    foods. Esther Peterson Daniel 286–295
    foods, determination 286–287
    foods, summary 32–33
    vegetable feeds 1024–1025
  deficiency—
    relation to body disturbances 9, 115–120
    relation to dental caries 121–123
    relation to food utilization 442–443
  needs of man—
    Lela E. Booher, Elizabeth C. Callison, O. L. Kline, Sybil L. Smith, Frederick W. Irish, and E. M. Nelson 221–271
    summary 23–30
  requirements—
    for animal nutrition and reproduction 485–487
    of beef cattle 538–543
    of chickens 816–817, 818
    of dairy cattle 633–637
    of egg production 806
    of gallinaceous upland game birds 914–916
    of horses and mules 773, 779–780
    of human body 220–271
    of livestock, limited knowledge 1057–1058
    of poultry 816–817, 818
    of swine 720–722
    of turkeys 816–817, 818
  therapy, misleading claims 142–143
Vitamin A—
  Lela E. Booher and Elizabeth C. Callison 221–229
  amount in milk, relation to quantity of carotene in feed 669
  concentration in butterfat, relation to carotene in feed 669
  content of—
    foods 222, 224
    milk 668–673
  deficiency—
    cause of hemeralopia 702
    effects 24, 223–224, 226, 538–539
    in chickens, symptoms 827
  discovery 221–222
  distribution in foods 224–225
  effect on—
    hatchability of eggs 791, 795
    male chickens 790
  feeding to chickens 823–824, 834
  function in human body 115–116, 223–224
  human requirements 23–25, 226–229
  in eggs, effect of hen's diet 792
  in foods, quantitative measurements 225
  International Unit 225
  potency, per gram of colostrum, from cows of various breeds on and without pasture 672
  pure, occurrence and properties 222
  relation to proper functioning of human eye 3–4
  requirements of—
    dairy cows 581–585
    foxes 877–879
    gallinaceous upland game birds 914
    young turkeys 836
  sources and description 23–25
  sources in foods 287–288
  supplements, effect on growth rate of young calves 633
  value in animal body 538–541
Vitamin B—
  complex—
    requirement of calves 542
    See also Riboflavin.
  content in milk 673–678
  deficiency, effects 673–674
  requirements of foxes 879
Vitamin B_1—
  O. L. Kline 229–235
  chemical nature 231–232
  crystals, properties 231
  deficiency—
    cause of beriberi disease 701
    diseases 230–231

Vitamin B_1—Continued. Page
  deficiency—continued.
    effects 25–26
    in chickens, symptoms 827
  effect on hatchability of eggs 795
  feeding to chickens 824
  function in human body 116
  human requirements 25–26, 232–235
  requirement of—
    cows 673–678
    upland gallinaceous game birds 914–915
  sources—
    and description 25, 26
    in foods 289–290
  synthetic, description 25
  values—
    Chase-Sherman unit 233
    International Units 233
  See also Thiamin.
Vitamin B_2—
  in colostrum, comparison to B_2 in later milk 677
  requirement of cows 673
  See also Riboflavin; Vitamin G.
Vitamin B_6—
  concentration in milk 676, 678
  use in control of pellagra 268
Vitamin C—
  Sybil L. Smith 235–255
  content in milk 678–682
  deficiency—
    cause of scurvy 702
    effects 26–27, 238
  discovery 235–236
  effect on—
    hatchability of eggs 795–796
    human body tissues 238–239
  function in—
    human body 116–117
    nutrition of cattle 678–679
  human—
    requirements 26–28, 235–255
    requirements, determination methods 242–243
  nutrition—
    blood test 241–242
    capillary-resistance test 239–240
    excretion test 240–241
    optimal, representation by saturation 243–244
  properties 236–238
  relation to infections 238–239, 253–254
  requirements—
    in disease 250–254
    in health 244–250
    of adults 247–248
    of children 246–247
    of infants 244–246
    of old people 249–250
    of pregnant and lactating women 248–249
  sources—
    and uses 26
    in foods 289
Vitamin D—
  Frederick W. Irish 255–259
  aid to mineral assimilation 193
  content of milk 682–684
  deficiency—
    cause of rickets 702
    effect on chick embryo mortality 799
    effect on growth in children 256
    effect on hatchability of eggs 791
    in chickens, symptoms 827
  [illegible]t on hatchability of eggs 796
  [illegible]ding to chickens 824–825, 834
  function in—
    animal diet 530
    human body 117–118, 255–256
  human requirements 28–29, 257–259
  requirements—
    effect on dietary constituents 443
    [illegible] beef cattle 542–543
    of gallinaceous upland game birds 915
    of human body 28–29, 257–259
    of young turkeys 836
  secretion in milk, effects of diet and exposure of animal to light 684
  sources—
    and abundance 28–29

Vitamin D—Continued. Page
  sources—continued.
    in foods 288
Vitamin E—
  E. M. Nelson 259–261
  deficiency—
    effect on chick embryo mortality 799
    in chickens, discussion 827
  effect on—
    hatchability of eggs 796
    male chickens 790
  feeding to chickens 825
  function in human body 118
  human need undetermined 260–261
  requirement of—
    beef cattle 543
    gallinaceous upland game birds 915
    rats 260
  sources in foods 289
  studies 29
Vitamin G—
  deficiency in chickens, symptoms 827–829
  feeding to chickens 825, 834
  function in human body 118
  requirements of—
    gallinaceous upland game birds 916
    human body 29–30
  sources in foods 290
  See also Riboflavin; Vitamin B_2.
Vitamin K—
  deficiency in chickens, symptoms 829
  function in human body 119–120
  requirement of beef cattle 542
  sources—
    and function 291
    need for research 825
Vitamins—
  conservation, suggestions 295
  determined and synthesized, description 703
  discovery, relation to diet-deficient diseases 701–705
  effect on hatchability of eggs 795–797
  functions in human body 115–120
  in hay, losses in curing 997–998
  in milk, and in milk production—
    C. A. Cary 668–684
    summary 64–66
  occurrence in foods 287–291
  undiscovered, additional research 705
Vixens, breeding, composition of rations, experiments 883
Volatile acids, formation in silage 1006

WALLACE, HENRY A., Secretary, foreword v–vi
Washington, forage crops, iodine deficiency 1038
Water—
  available to crops, effect on their nutritive value 410
  consumption, calves from 3 to 24 weeks old 637
  fluorine content, dangers 21–22
  function in human body 105–107
  requirement of—
    calves 637–638
    dogs 862
    gallinaceous upland game birds 911
    horses and mules 779
    human body 8
    poultry 825–826
    swine 722
  supply—
    filtration for removal of fluorine 213
    fluorine concentration, result 212–213
    iodine deficiency, result 212
WAUGH, F. V.: Subsidizing Consumption of Foods 392–396
Weight, body, control by foods, danger 12
West Virginia, forage crops, calcium deficiency 1035
Western States, swine production and feeding practices 729
Wheat—
  bran, composition and feed value 1021
  germ—
    source of riboflavin in diet 264
    vitamin content and value 231, 1026

Page

- Whey—
  - composition and total digestible nutrients 602
  - digestible nutrients and feed value per 100 pounds, comparison with fresh skim milk 602
  - fresh, feeding to dairy calves 606-607
  - milk, riboflavin content 261-262, 264
  - use in making silage 1010
- White House Conference on Child Health and Protection, report on iron content of infants 208
- Wine production, role of micro-organisms 347
- Wisconsin, forage crops—
  - iodine deficiency 1038
  - phosphorus deficiency 1035
- Women—
  - anemia, occurrence and control 206-207, 209-210
  - copper requirements 211
  - farm, energy output 163-164
  - food energy, daily allowance suggestions 172
  - iron requirements 205-208
  - phosphorus requirement 194
  - pregnant and lactating—
    - calcium requirements 192
    - phosphorus requirements 195
    - vitamin C requirements 248-249
    - vitamin D requirements 259
  - relative energy allowances, recording schedule 168
  - vitamin B_1 requirements 234
  - vitamin C, daily allowance 255
  - weight averages according to height and age 161
- Woodward, T. E.:
  - Figuring the Rations of Dairy Cows 592-596
  - Pasture and Range in Livestock Feeding. With P. V. Cardon, W. R. Chapline, E. W. McComas, and C. R. Enlow 925-955
  - The Nutritive Value of Harvested Forages. With W. H. Hosterman, P. V. Cardon, and E. W. McComas 956-991
- Woodward, Thompson E.: Nutritive Value of Miscellaneous Feeds. With Earl W. McComas 1017-1026
- Wool—
  - fiber, effect of nutrition plane 496-497
  - growth, effect of carbohydrates in diet 499-500
  - production—
    - cystine requirements 498-499

Wool—Continued. Page

  - production—continued.
    - energy and protein requirements 498-499
    - nutritional factors affecting 500
    - relation to nutrition. John I. Hardy and Imogene P. Earle 492-500
    - relation to nutrition, summary 52
  - structure, description 493-494
- Workingman, family purchases of 58 foods, estimated retail value and equivalent farm value 393
- Wounds, healing, effect of vitamin C 238, 252-253
- Wright, P. A.: Variations in the Composition of Milk. With E. F. Deysher and C. A. Cary 639-648
- Wyoming, forage crops—
  - iodine deficiency 1038
  - selenium excess 1040

- Xerophthalmia, cause 223-224

- Yearbook, 1939, general lay-out, review 5-6
- Yearbook Committee on Nutrition VII
- Yeasts—
  - cause of organic decomposition 341-342
  - growth—
    - in fruit juices, preventive measures 342-343
    - in milk, preventive methods 345
    - on fruits, preventive measures 342
  - role in bread making 348
  - source of riboflavin in diet 264
  - value in cure of pellagra 268, 269
- Yellow coloring, association with vitamin A 222, 224, 225

- Zeller, J. H.:
  - Nutritive Requirements of Swine. With N. R. Ellis 706-722
  - Practices in Swine Feeding. With N. R. Ellis 723-745
- Zinc—
  - content in milk 647
  - occurrence in foods 279
  - occurrence in human body and necessity in foods 216-217
- Zirconium, occurrence in human body 220

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